TELESCOPE MAKING 28

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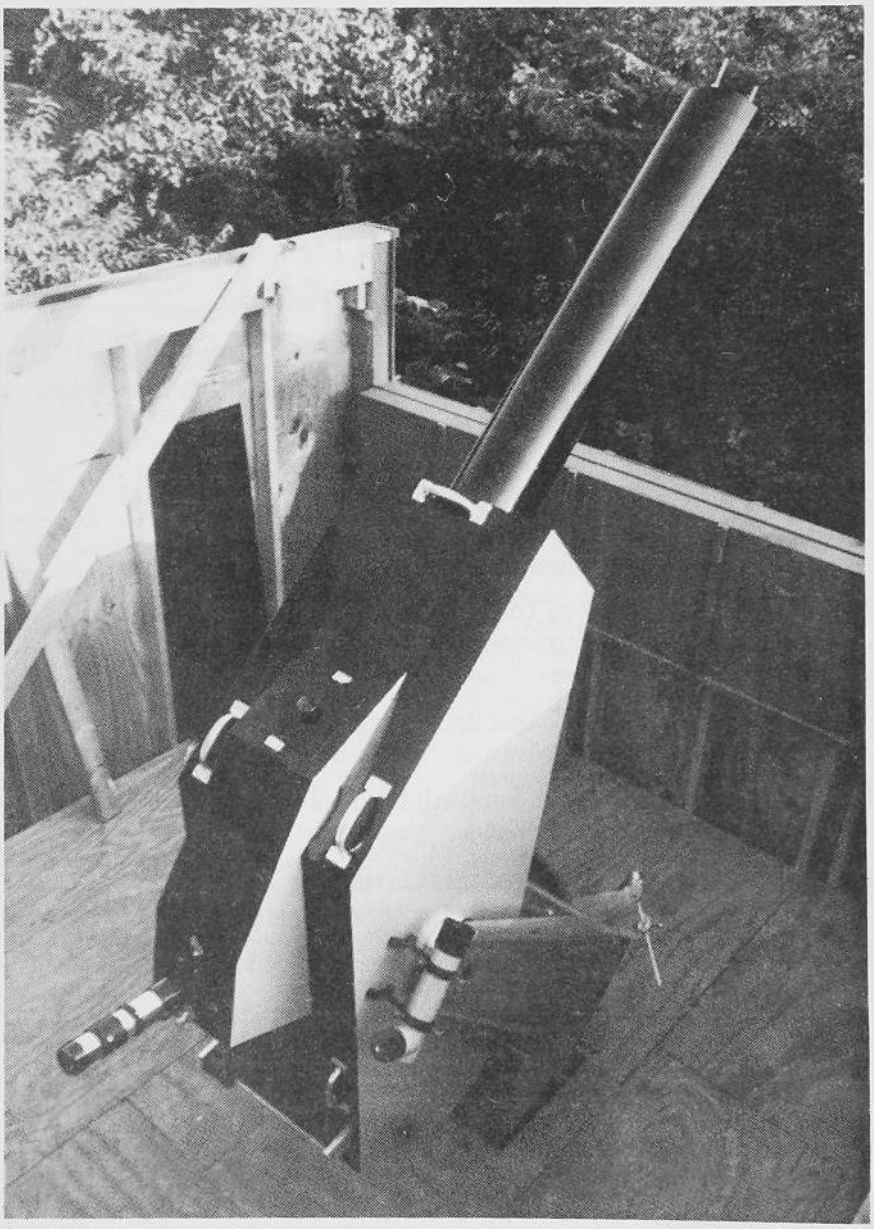
The magazine *for*, *by*, and *about* telescope makers!

Fall 1986

TRI-SCHIEFSPIEGLER



TELESCOPE MAKING

The magazine *for, by,* and *about* telescope makers!

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Editorial

Telescope Making is back on track at long last — this is the first issue to come out on the scheduled date in nearly two years. I time sending mechanicals to the printer by the solstices and equinoxes, so *TM#28* is going out a bit after September 23, and *TM#29* will go out around December 22.

On the other front, Comet Halley is now deader than a doornail as far as the general public is concerned. Work at ASTRONOMY is getting back to normal, although the magazine has remained at 112 pages or more, considerably larger than the pre-Halley norm of 88 pages.

Despite our erratic schedule, I have received a great many supportive letters. Thank you. It's obvious that *TM* readers want *TM* to continue, and it will. I must stress that with any small-circulation, special-interest magazine, your subscription order and your subscription renewal are very important. They're what keep this publication alive.

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On the back cover of this issue is our new back issue ad, with new back issue prices. *TM* has maintained a very unusual policy for a small magazine: we've kept every back issue in print. In most cases, the remnant of the original press run sold out years ago, and we've had to go back to press with short run orders. If you know anything about printing at all, you know that the shorter the print run, the higher the cost per copy. Add to this the cost of handling small orders, and the cost of warehousing boxes of *TM* back issues for three or four years, you'll see why we've been forced to increase prices.

While I'm not happy with a $4 per back issue price, the alternative is to let back issues go out of print one by one. Because of the the efficiencies of handling and fulfilling them, we have been able to keep the price on large orders (twenty-five copies or more) equal to buying the same number of current issues, so if you've only recently discovered our little magazine, it's still possible to obtain a complete backfile at a pretty good rate ($3 a copy). If your order doesn't come up to twenty-five back issues, you might consider pooling your order with that of some friends. In any event, I think I'm safe in saying that back issue prices will not go down in the future, especially since it will become necessary to reprint more back copies in short print runs. If you want the complete set, order now.

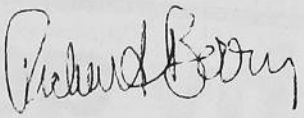
——

Precision optical systems are making a resurgence these days. I suppose what's happening now is that we've all had our turn at the eyepiece of a humongous telescope of some kind and have seen our fill of galaxies and dark nebulae, and the belts and bands and little white ovals of Jupiter seem once again new, fresh, and interesting. And, having twiddled the focus knob in that vain search for a crisp image, we find telescopes that have razor-sharp optics appealing.

I'm sure the deep-sky folks are already muttering. "Well, what's gotten into *his* head that he's even *thinking* such thoughts, let alone writing them?" I suppose my answer is, "I'm just watching the trends and writing about them. What's happening is happening."

This issue of *TM* presents three articles on telescopes capable of giving perfect or near-perfect optical performance, and another article on the importance of smoothness for precision optics. I haven't had the opportunity to use either of the 12.5″ Tri-Schiefspieglers, but I have observed with A.L. Woods' 6″ TCT and the famous 4″ make by Bob Cox. These instruments are remarkable for their crisp imagery over the whole field, even without extraordinary eyepieces. At Astrofest last week, I saw one of Roland Cristen's new 7″ f/9 triplet objectives. The definition of one of these lenses has to be seen to be believed. Roland is unusual in that he's willing to share his "secrets" with the amateur community in a way few manufacturers are.

With Dick Suiter's computer program you can grind out all the rough mirrors you'd ever want to, and evaluate their image quality. Although decibels aren't the usual units of the optical profession, you should be able to get some feeling for the vertical scale by comparing the perfect pattern with the best Airy disk you've ever seen. For those who refuse to key in and debug programs, don't ask Dick to send you a diskette with the program on it. He won't. Instead, send me a formatted IBM diskette with a self-addressed stamped diskette mailer. I'll copy the program onto your diskette and drop it back in the mail to you. If you'd like to thank TM for the time and effort of making copies, send us two diskettes. That way I'll have some spares on hand for the moochers who didn't read this and write for a freebie.



Richard Berry

Letters

Telescope for 'Checking Out'

Dear Sir / With two kids, my wife working part-time, and the weather, it's tough to get to look much through the telescope these days. Also, there aren't very many amateurs in this area and phone calls get expensive fast. As a result I guess I don't really know many things about the limits of performance.

I've ground six optical surfaces in my life, although the first probably shouldn't be included. It was that bad! Anyhow, I was fourteen and learning on my own. My last attempt was an 8″ f/6.8, and I'm wondering about it. The polishing could have been better though I think the surface is good. On March 15, 1986, I split A10075 in Hercules. It's listed as 0.7″ in a book I have. I used a 6mm Ortho for 230x. There was dark sky between the two stars, but they were split, though not much. I was and am pretty happy with it. Is this doing pretty good, or should I expect this type of performance? The seeing at the time was 7 on a scale of 10. Transparency was 3 to 4 on a scale of 5.

Planetary performance is rather low contrast. I suspect this is because of a poor polish job, but it may be because of low altitudes on Mars and Saturn this summer.

I've got a suggestion for other telescope makers. I like making telescopes and have more parts around than I probably should. I refigured a 6″ f/5.6 last year and rebuilt it this year. I've split both components of Epsilon Lyra at about 70. Anyway, it's up at the library now, and with the weather getting a little better, the scope is starting to get "checked out."

For those who are suspicious of people offering a night under the stars, and for those who don't like a hard sell, checking out a telescope from a library may offer people a chance to explore on their own. It's certainly an opportunity to use and find out about equipment without getting "burned" financially. The scope is built for low power. For those with extra parts laying around, I suggest that this may be a good place to put them to use, and maybe to reassure others that a telescope is within their abilities.

Andrew M. Sorenson
Route 4 Box 4A
Jefferson, IA 50129

— The 8″ scope sounds like it's doing very well for a telescope of that aperture. I certainly didn't have many good veiws of Mars and Saturn this summer, and I felt that their low altitudes were a significant part of the problem. Jupiter has been more rewarding, and gets higher.

Loaning a spare telescope to a public library is a delightful idea. I wish you all the best in this and hope that other telescope makers with telescopes to spare will do the same.

Jan's 'Good Guys' List

Dear Richard / In *TM#21* about two years ago I identified a list of "good guys" in the astronomical equipment mail order business. The list was in answer to a number of horror stories about companies providing poor service or products to your readers. Membership to the "good guy" list was earned, not for the largest ads, but for consistently providing service, quality products, and personalized assistance above and beyond the call of duty. Businesses like these who "go the extra mile" deserve our patronage. They earn it every day. It is time to update that list.

Number One. Meade Instruments is still at the top of my list after many, many direct and indirect orders. Their products are of consistently high mechanical and cosmetic quality, their service is just as fast and friendly as ever, and they aren't too busy to answer questions. Honestly.

Number Two. Al Nagler and his TeleVue Optics have moved into a solid number two. He has expanded his line of *superb* eyepieces and accessories and offers a fine 4″ refractor. No matter what size or type telescope you own, but especially owners of fast Dobsonians, you aren't exploiting the full potential of your optics if your eyepiece isn't from TeleVue.

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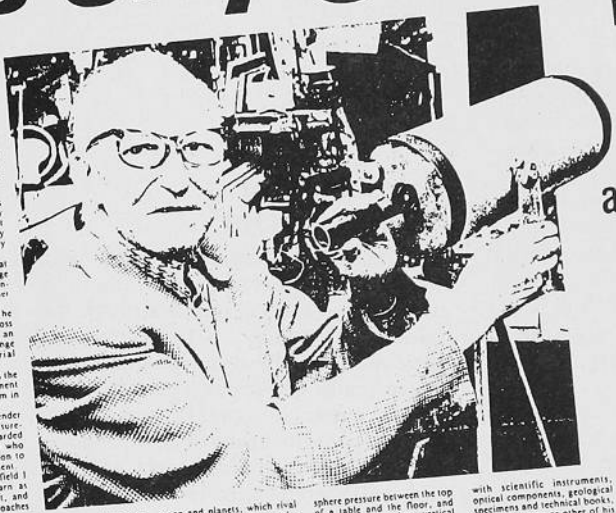
An Interview with Horace Dall

Fame at last for the man who likes to get to the top

The shy genius

No one in the world knows as much about optics, says Patrick Moore



MANY people remember Horace Dall for the forty-eight years he worked at George Kent in Luton.

It is only now at the age of 82, that his name is becoming known outside his circle of specialists, especially as he was recently featured in the *New Scientist* and the *Luton Post Echo*.

"I first became interested in optics when I bought a spyglass telescope in my early teens," says Horace. "I found that my hobbies, which included photography as well as optics, often helped me in my work at Kent."

He joined the design department at George Kent in January 1918, at the age of 17, after serving a three-year apprenticeship with an aircraft firm. His father also worked for George Kent.

It was during his time there that he developed the Dall Tube, a low-head loss flow-measuring device which is an important part of the current range manufactured by Kent Industrial Measurements at Stonehouse.

He retired from Kent in late 1965 as the company's senior flow development engineer, having led the research team in his field for more than thirty years.

In 1977 he was awarded the Callender Silver Medal by the Institute of Measurement and Control. The medal is awarded annually to an engineer or scientist who has made a considerable contribution to the art of instruments or measurement.

"I like to get to the top in any field I enter," says Horace. "First I learn as much as I can about that subject, and then I start to think of fresh approaches and ideas."

During his time at Kent he was also patenting the results of his spare-time inventing.

In 1930 he was asked by Churchill's cousin, Captain Randolph Wilson, to help him set up a laboratory, and this led to patents in an early TV system, and in 1933 he patented a variable-density technique of optically recording sound on film, and before this in 1924 a patent in the radio field.

During the Second World War Horace was one of a dozen experts called to Farnborough to examine the wreckage of a V2 rocket that had crashed in Sweden on a test flight.

From an examination of the rocket's combustion chamber and fuel pumps he was able to calculate the V2's thrust and hence its range, before one was ever fired at England.

Horace especially chose the site on which his home stands to suit his hobbies.

"I looked all around Luton to find the plot of land with the best outlook, so that I could install a camera obscura in the roof."

The house was built in 1934, and in 1935 the camera obscura was installed. In 1937 several powerful telescopes of his own making together with an observatory in the garden were completed.

"The camera obscura drew visitors from all over the world," he says. "As well as viewing the surrounding landscape, I also use it for astronomical observing. It can project an image of the sun seven feet in diameter revealing fine details of its surface."

In the observatory he often takes photographs of the sun, moon and planets, which rival those taken by bigger telescopes in professional observatories.

He joined the British Astronomical Association in 1925 which later led to his friendship with Patrick Moore.

"There is no one in the world who knows more about optics than Horace, but he has never really been recognised," says Patrick. "His genius is equalled only by his shyness."

One of Horace's more remarkable achievements is his machine for micro-writing, which has produced writing on glass to the scale of 250 bibles on a square inch, which equals one bible on a pin-head. But Horace dismisses the feat as "only a bit of fun".

Another achievement is a barometer so sensitive that it can record changes in atmosphere pressure between the top of a table and the floor, and even a few inches vertical movement.

And an optical testing method he invented, now known as the Dall Null Test, is used by opticians throughout the world to check the shape of their astronomical mirrors.

He also holds the record for making the most powerful single-lens microscope, capable of magnifying 1000 times, and he has made several pocket telescopes, one of which is four inches in aperture and weighs eight ounces.

It folds flat to fit into his pocket, has been all around the world with him, and has never been spotted by a customs official.

Horace still spends many hours a day in his study, which is filled from floor to ceiling with scientific instruments, optical components, geological specimens and technical books, working on one or other of his hobbies.

His study also houses the souvenirs from his travels and boxes of photographs reaching back sixty-five years.

"Travelling is my other great love," he says. "Being so familiar with the sky and space, the earth seems quite small in comparison.

"I've always wanted to explore as much of it as I could, particularly the parts that were difficult to reach and least visited."

Horace holds the record for being the first person to cross the interior of Iceland on a bicycle, in fact on any wheeled vehicle.

"I did the trip in 1933, when the interior was totally unmapped," he says. "It took five days and I had just 1¼lb of food.

"It was very tough, for it is mostly volcanic or rocky desert, many rivers to cross and there was no trace of human life, but it was very exciting."

He also pedalled his way through the mountains and deserts of Morocco, Syria and Tunisia during the early 1920s.

"I was arrested several times as a spy by the Foreign Legion, they couldn't believe anyone would want to spend their holidays cycling across a desert in temperatures of 48°C."

Raleigh Cycles were so impressed by his adventures on their machines that they produced a special advertising leaflet filled with his photographs saying that a Raleigh bike will take you anywhere, using Horace as the example.

He is now on his eighth passport, having left England 82 times, and he has a photographic record of every trip.

He met his second wife, Helena, in a cafe in Patagonia, South America in 1968, and, finding they were both seasoned travellers, they married later that year, with Patrick Moore as best man.

"Since then we have roughed it around the world including Cairo to Cape overland via Ethiopia and Kalahari sleeping at times in caves, lorries, crowded railway cars and even mud-huts. Our trips together have included Mongolia and the Himalayas," he says.

Few people at Kent knew how Horace spent his spare time. "They probably would have thought me a little eccentric," he smiles.

"I never believed that the things I got up to would be of interest or importance to other people other than fellow hobbyists. It was just my bit of fun."

BOOST FOR EXPORTS

KENT Industrial Measurements, Stonehouse, has received three significant export orders for delivery to the power, water treatment and paper industries in Botswana, Brunei and Norway.

The orders cover Kent Veriflux flux sensing electromagnetic flowmeter systems and a total requirement of thirty-one systems in sizes ranging from 10mm to 900mm.

The Botswana order received via Kent Instruments (SA) in Johannesburg, is for water metering instrumentation at a power station complex. The Brunei systems, ordered via George Kent (Singapore), are for a water treatment plant, and the Norwegian order for installation in one of Norway's largest pulp and paper mills.

THE STEEL CONTROL

PICTURED here at British Steel Corporation's Port Talbot works in South Wales, is a dual centralised display system and rack-mounted control system from the P4000 range. Supplied by Kent Process Control, Hitchin, the scheme monitors and controls a two-strand continuous steel-slab caster. The system achieves a high availability of the 500 plant items connected to it with individual instrument displays and by duplicating the input-signal channels.

WATER LAB FOR CZECHS

KENT Industrial Measurements, Chertsey, are to supply a packaged water quality monitoring laboratory for a treatment plant at Jihlava, Czechoslovakia.

The laboratory, housed in an insulated cubicle to withstand extremes of temperature, is fully equipped with a range of EIL on-line analytical instrumentation, including the latest Kent EIL 8021 fluoride ion selective monitor, 9180 pH monitor, and an ultra filtration system.

The equipment will monitor the continuous quality of potable water and ensure the supply of drinking water to nearby Brno.

The order was placed via George Kent (Europe) in Vienna.

On November 24, 1983, while visiting England, Dr. Richard A. Buchroeder ("Dick") visited Horace Dall and recorded the following interview:

Dick: First, when were you born?

Horace: On January 5, 1901, the fifth day of the twentieth century.

Dick: When did your interest in optics start?

Horace: I really don't remember. I saw Halley's Comet in 1910 but can't remember too much about it. It's quite possible it was the great daylight comet of the same year that I saw instead. Father was a little bit interested in optics and showed me objects under a simple microscope. Somehow I was always interested in anything that magnified or reduced optically. I bought my first telescope, a 16x spyglass, when I was about 12 years old. I soon wanted to increase the power and with a lens I found somewhere or other put the power up to about 40x. I remember climbing out on the roof outside my room and watching the Moon rise with the 40x, but of course the aperture was only one inch so it wasn't exactly brilliant, but it worked!

Dick: When did you start making your own telescopes?

Horace: Not long after the 40x spyglass. I used spectacle lenses and cardboard tubes, enjoying myself as so many young people have.

Dick: When did you get a large aperture instrument?

Horace: When I was 16. I bought a second-hand 2.25" achromatic object glass with which I was able to make some very good drawings of Jupiter.

Dick: Did you meet any astronomers or optical people to help you along.

Horace: No, it was all on my own. I had a friend who had similar interests in astronomy and I put an ad in *English Mechanic*, "Wanted: 6" telescope. Must be reasonable!" A reply from a well-known amateur astronomer in Manchester, William Porthouse, informed us he had not a 6" but an 8.5" Calvert and he let us have it for 12 pounds plus postage. After a year my friend dropped out of astronomy and I bought up his share of the telescope.

Dick: So how long was it before you decided to do your own mirror making?

Horace: I had information on the Foucault test from articles in *English Mechanics*, and also the Rev. Ellison published some articles in the same magazine. I got itchy about doing my own, and in about 1925 made my first 6" mirror. Everything went according to the book. I got it spherical and then parabolized it. I thought, "This is damn easy, and it has a good figure too."

I overcorrected it *for the experience* and brought it back to a paraboloid. It was an f/8 focus. Later I sold it. I then promised myself that I would not get rid of the Calvert until I had made one at least as good. I soon made a 9" which fit in the same tube as the Calvert mirror. I had trouble with the metal tube and air currents, as there was less than½" clearance between the glass and tube wall.

Dick: What was your source of glass?

Horace: I saw an ad for surplus porthole glass in *English Mechanics*. I bought close to a quarter ton of it. Some blanks were up to 16" in diameter, and I've still got some left.

Dick: What did you do with the glass?

Horace: I first made a 14". Then in 1937 I made a 15.5" on a 16" disk and mounted it in an observatory in my backyard. The glass has a thickness of 1.5" at the edge and 1.25" at the center.

Dick: Did you have any trouble supporting it?

Horace: No. From the beginning I used a multi-pad support to prevent distortion due to the weight and thinness of the glass.

Dick: Did the Rev. Ellison give any information on how to do this?

Horace: No. He advocated mirrors with a 1 to 6 thickness ratio, so I had to figure it out for myself. Once I found the proper support system that worked well I began to advocate thin mirrors for telescopes.

Dick: Did the plate glass as opposed to Pyrex bother you in any way?

Horace: No, not at all. I knew that a falling gradiant would tend to overcorrect a mirror so, like Ellison, I always left them slightly undercorrected by some 10 to 30 percent!

Dick: What did you do for silvering, just use the Brashear process?

Horace: Yes, it was described in Ellison's paper, and that is the information I used.

Dick: Isn't his process the one in which he warns about being careful not to let the solution turn into silver fulminate, which is highly explosive?

Horace: Yes it is, but I never experienced trouble. In fact, I purposely tried to make some with no success.

Dick: What kind of a lifetime did you get out of your coats?

Horace: Usually no more than six months.

Dick: Did you meet the Rev. Ellison?

Horace: No, never met him.

Dick: I wonder where he got his experience, did he learn it all by himself?

Horace: He got it from other people that preceeded him. There was George Calvert, for instance, and the whole story of his telescope making is covered by the old issues of *English Mechanics*.

Dick: How many amateur telescope makers do you think there were when you got started? Were you aware of many in the country?

Horace: That's difficult to estimate, but I could imagine there could have been some hundreds!

Dick: Did you correspond with local or other amateurs?

Horace: No, not really. But I did have some local friends with whom I occasionally shared my hobby.

Dick: Did you spend much time observing with these optics?

Horace: Oh yes, I've made many observations over the years.

Dick: When did you get into what one might call semi-professional optical work, as with small lenses?

Horace: There was nothing professional about it at all.

Dick Well, one might say it was professional by default. How did you mount the porthole glass mirrors?

Horace: I made square wooden tubes and bought mountings for them, second-hand mounting, through *English Mechanic*.

Dick: When did you get all the equipment you now have, a precision lathe, for instance.

Horace: About 45 years ago, back when I was in my 40's. They were not specifically for telescope work, but for any instrument work I might do. My father was an instrument maker so I was brought up in the atmosphere of instruments.

Dick: Did your parents encourage you in your astronomical interests?

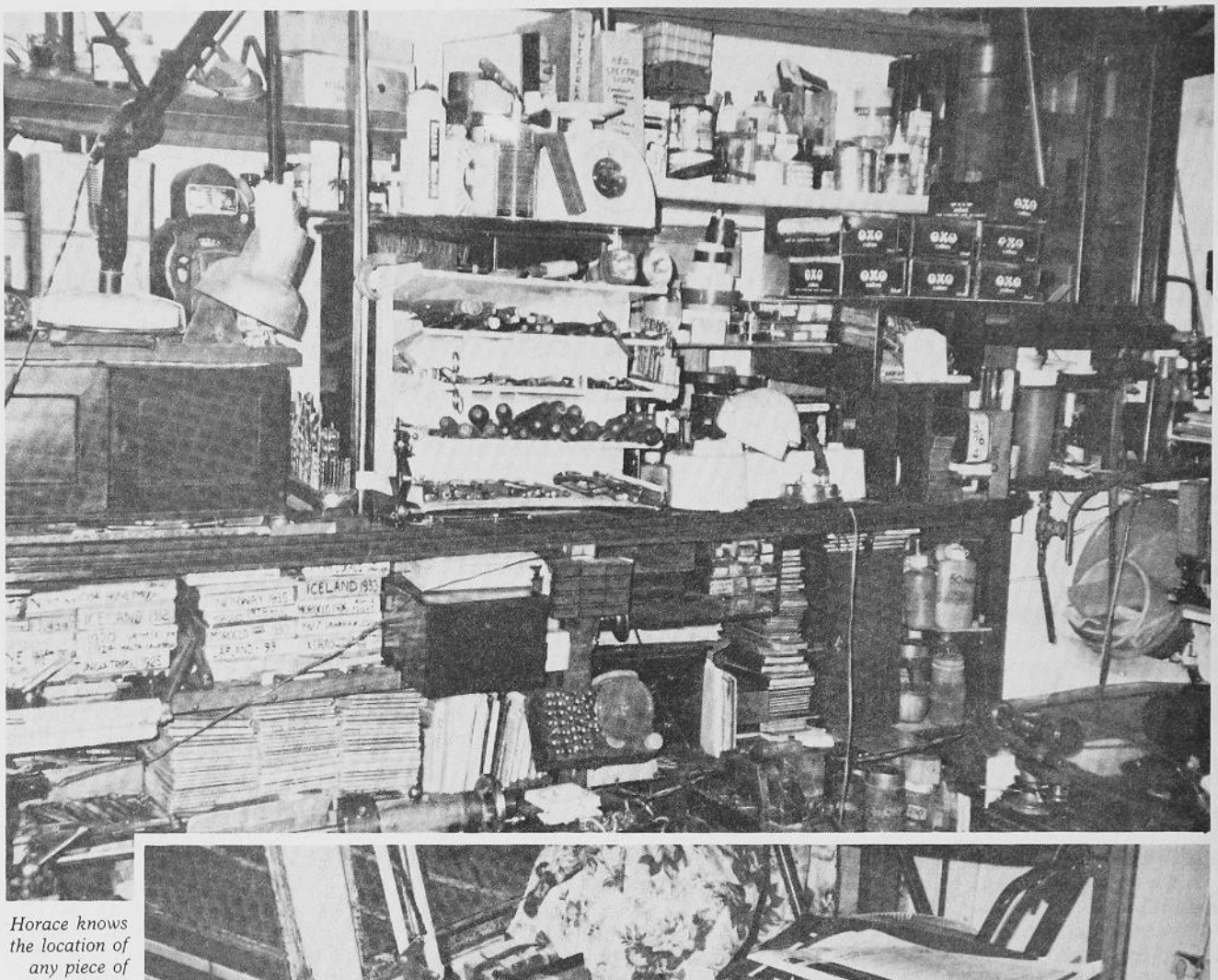
Horace: Father gave a passing interest kind of support, but not an active one. My interest and enthusiasm was pretty much all my own.

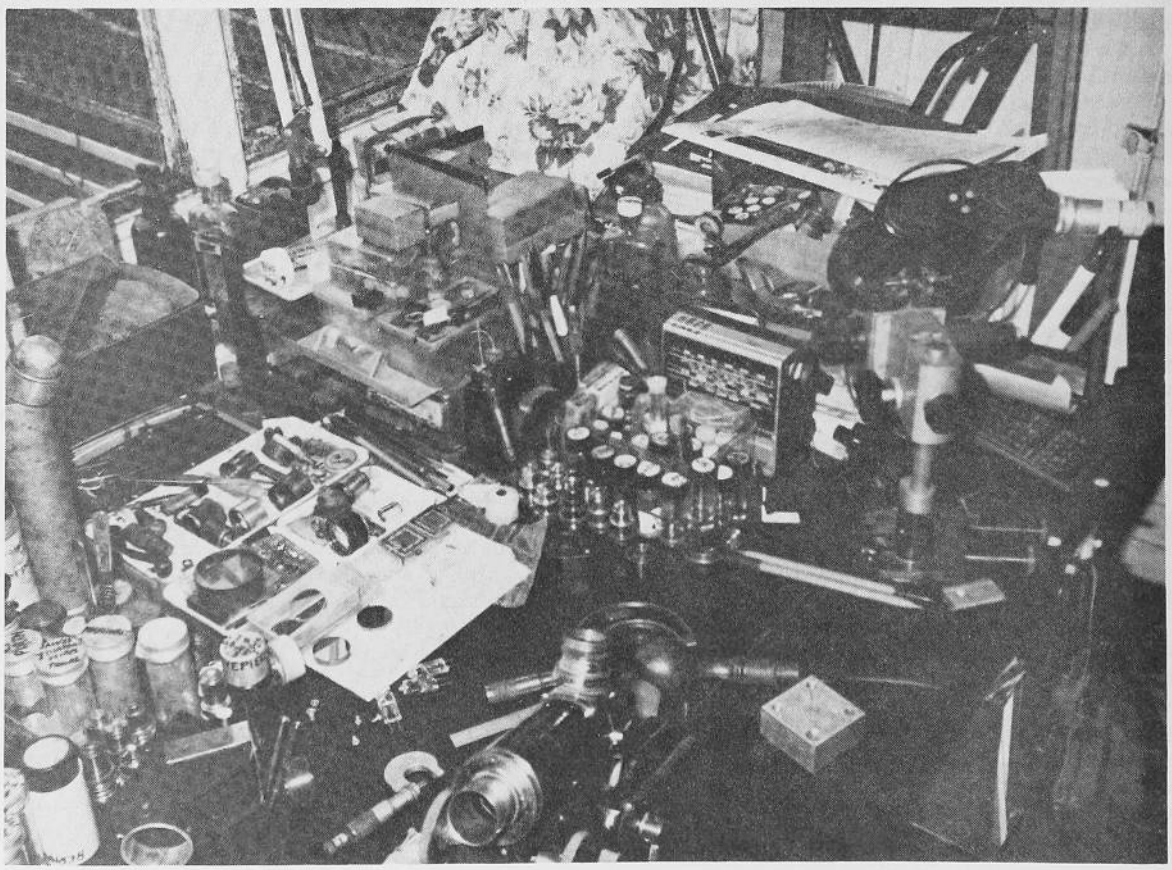
Dick: When did you publish your first work, and when did you start submitting articles to *English Mechanic* and so forth?

Horace: I never submitted to *English Mechanic*, and when the original editor died in the 1920s the publication folded up.

Dick: When and why did Albert Ingalls contact you?

Horace: Because I started making Tolles eyepieces in 1925, a single bit of glass. They are very easy to make, and I was making my first lenses. By 1928 I was fairly proficient at making them so I put an ad in the *BAA Journal*, *Scientific American*, and *Popular Astronomy*. I got quite a large number of replies from them, in fact almost too



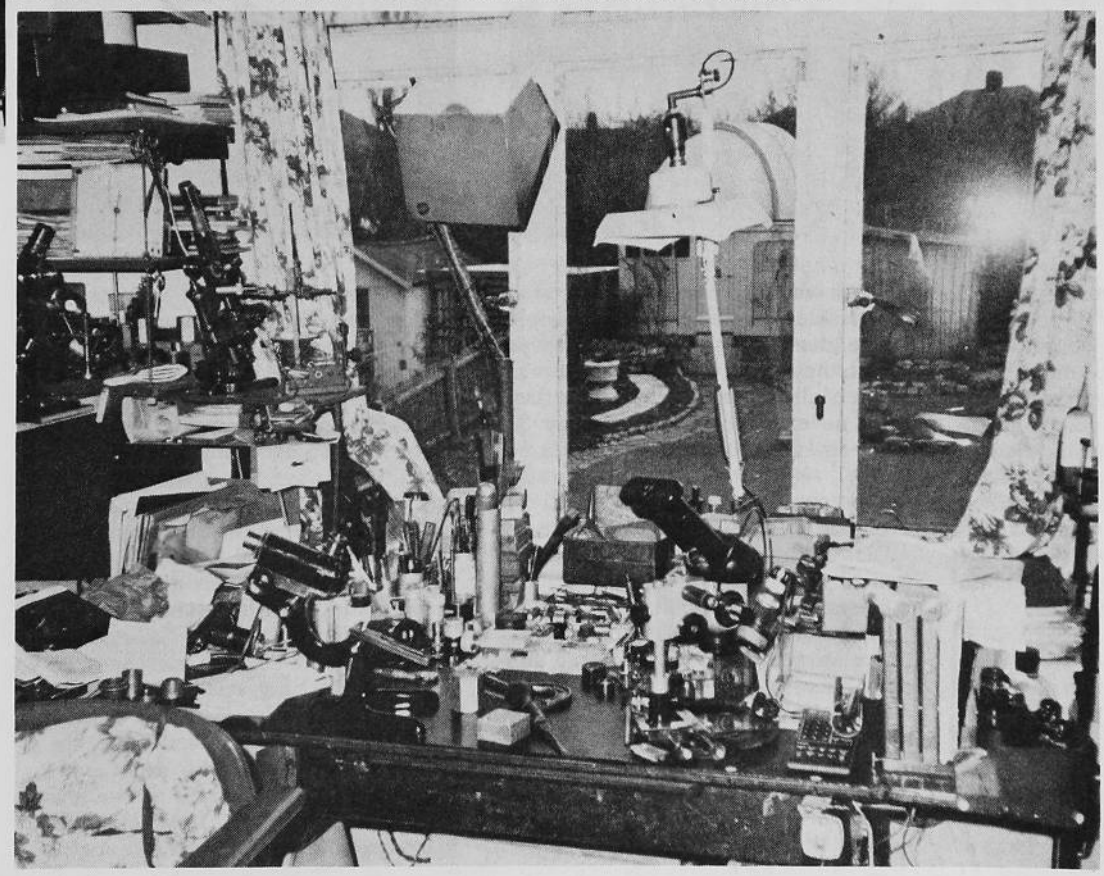


Horace knows the location of any piece of equipment — despite the apparent chaos!

In the roof. Small laser at left. When the mood takes him, Horace projects a spot of light on the sidewalk, and observes the quaint behavior of the natives when they examine said spot. Mirror test bench at center background.

Horace leading the way up to the roof space.

The observatory from the window of Horace's den.



photos by Jim Houghton

many. I also had an agreement with Tinsley in California to supply all their eyepieces.

With the Depression in America, I was requested to reduce my prices, but I said "No." I was glad to get out of supplying eyepieces. My part-time hobby of making and selling eyepieces was taking up too much of my spare time. Of course, I didn't restrict myself to Tolles eyepieces, but also made Kellners.

Dick Did you do all this by yourself? How did you find the time to do all this?

Horace: Nobody helped. It was a one-man operation. As for time, if one wants to, one can always find time for something.

Dick: Did you have dreams at that time of becoming a professional optician?

Horace: Oh, no. I was working in *drawing* and had been working since I was 14, during the First World War. From 1914 to 1917 I worked in a drawing and design office on aircraft. I thought I would be going into the aircraft industry and was going to night class. My teacher in applied mechanics, hearing I had given notice at my plant, informed me he could get me a position at George Kent in Luton, so he changed my mind about the aircraft industry. I started in 1918 and stayed with them until my retirement in 1965.

Dick: So you worked at Kent with flow meters and your hobby was optics.

Horace: Yes, but occasionally there was optical work. During World War II, when we couldn't get projectors for checking screw threads, I designed one for them and made the lenses myself.

Dick: Which do you prefer working with, lenses or mirrors? Or do you draw any distinction between them?

Horace: I enjoy both; each is its own challange. Parallel with my interests in telescopes, I was intrigued by microscopes. The small lenses in microscopes contrast well with the large surfaces of mirrors. I bought my first microscope in 1917, and as soon as I learned to make lenses, I learned to contribute to the practical optics of the microscope.

Dick: Was it the use of the microscope or just the optics of the instrument that interested you?

Horace: The performance was my interest and I found viewing fungi a fascinating hobby.

Dick: What have you done with the optics of the microscope?

Horace: I have always been interested in getting the utmost out of a microscope, in getting high resolution. The last war encouraged my interest in high resolution. When the Leitz people in London heard I did microscope optics, they asked if I would undertake repair of all their optical stuff since they could no longer send it to Germany. So every few days a parcel of lenses came along — photographic lenses, microscope lens, and occasionally I even had to make prisms for them.

Dick: Where did you make these optics?

Horace: Right here. That table is an optical workshop table, while upstairs I have an optical bench, collimator, and other accessories.

Dick: Have you devised any new microscope objectives besides the single element microscopes of 400 to 500 power?

Horace: No, but I have aspherized some of them to improve performance.

Dick: How large are these lenses you aspherized?

Horace: Oh, about ¼" or so in diameter.

Dick: Was that difficult?

Horace: Rather, but usually I achieved the performance I wanted in an hour or so of work.

Dick: Your testing is basically like star testing?

Horace: Yes, in and out of focus, or knife-edge testing.

Dick: What materials do you use in your microscope lenses?

Horace: I used to use glass, but in high power objectives the possibility of getting scratches on them due to the small clearance between the lens and microscope cover glass led me to go to gem stones, like spinel. I made my own tools for cutting out my lens blanks, and have made lenses as small as one millimeter in diameter.

Dick: You liked working with these microscope-size optics?

Horace: Well, it's interesting and a worthwhile challange.

Dick: To get all your regular work and hobby interests done you must keep late hours?

Horace: I have always been a late retirer. I usually retire about 3 a.m. and rise at 8 a.m., in fact, I still keep these hours. Now, with the years accumulating, after a mid-day meal I take a short rest.

Dick: Getting back to telescopes: in the Dall-Kirkham design, how did Kirkham get involved?

Horace: Ingalls gave it that name, but I was the first one to make one of those telescopes in about 1931. I did quite a few before I contacted Ingalls. Ingalls had a group of people with whom he

corresponded, and he passed around interesting letters that he received to them. When I wrote of my spherical secondary Cassegrain, he passed the letter along to Kirkham and Hindle in England. Hindle scrawled *Nonsense*! across my letter and returned it to Ingalls. All of the Americans Ingalls passed the leter to agreed it was alright. I still have the Hindle remark in my upstairs collection. It's in a file I call "The Nonsense File".

Dick: Did you ever meet Hindle?

Horace: No, never. He lived in Manchester, about 200 miles from Luton.

Dick: Had you ever heard of Hindle?

Horace: Oh yes, he was one of the early contributors in the beginning to *English Mechanic*.

Dick: What was Alan Kirkham's contribution to the design?

Horace: He wrote to Ingalls presenting the mathematical formulae; he put it into mathematical form for the first time. I had not sent my derivation to Ingalls.

Dick: How did you feel about the double *recognition*?

Horace: Oh, it was alright. Kirkham was responsible for encouraging interest in the subject. We did have one exchange of correspondence.

Dick: Did you have much correspondence with American amateurs?

Horace: Most of my correspondence was with Ingalls, who sent me letters for comment. He was the father of telescopes in America, along with Porter, perhaps. I did have some correspondence with John Pierce in Springfield, Vermont. My first aluminizing was done by the Dudly Leroy Clausing Company.

Dick: When did you first go to the United States?

Horace: Not until I retired in 1965. I retired from Kent the day before Christmas, and the next day booked a flight around the world. When I got to the United States, I visited San Francisco then went down to Los Angeles and visited my good friend, Roger Hayward. One of his friends took me to Mt. Wilson and Palomar. At Mt. Wilson the grounds were closed to the public at the time, but I contacted an amateur who worked there, Tom Cragg, and had a special tour. I also visited Disneyland. It was good for kids, but was an unusual place.

Dick: I would like to go back and ask you about the Dall Null Test for paraboloids. When did you do that?

Horace: That was about 1945, I suppose. It was a successful test, so I wrote a paper to the BAA about it. I called it "A Null Lens for Paraboloids." Then Ingalls saw it and asked if he could publish it in the ATM book.

Dick: What led you to create that test?

Horace: Simply that I knew the spherical aberration of a lens was opposite that of a mirror, and that you could obviously balance the two.

Dick: How did you derive the aberration and know what lens to use with the test?

Horace: By ray-tracing. I could calculate the spherical aberration of a plano-convex lens. Things were worked out by first order theory and from experience. When I visited the United States I found many optical shops and amateurs using this test.

Dick: Upstairs you have a spherical collimator with a negative compensatng lens. When did you work that out?

Horace: About at the end of the war — and that, incidentally, is an even simplier approach than the positive lens.

Dick: Did you read any of the articles on the Maksutov by the Russians, or by Bowers?

Horace: Well, I am not very good on reading such material. I prefer to work designs out on my own, sort of work them up out of the blue.

Dick: How active are you with amateurs today? I know you're running for a council postion in the BAA. In the election for the council in the BAA it lists the following after your name: "A member since 1925, council 1950 to 1953, 1954 to 1957, 1958 to 1961, 1962 to 1965, 1967 to 1970, 1971 to 1974, 1975 to 1978, 1979 to 1982, awarded the Walter Goodacre medal in 1967, special interests solar prominence and planetary photography, designing and making complex telescopes for travel, advises the instrument section on technical matters, has contributed many papers to the Journal and has worldwide contact with amateurs giving help in solving their problems."

Horace: I give talks occasionally for groups. Last year I gave about three.

Dick: Can you tell me what your observing program is?

Horace: I am not too greatly interested in deep space. At my age, and following a cataract operation, my eyes are not in the same condition they were when I was young. I have about two diopters of astigmatism and I compensate in observing by having a very small exit pupil.

Dick: How much observing is possible in this climate?

Horace: If one observes in the hours just before dawn, the sky is clear at this time more than otherwise. I get one or two observations in a week. Every time the Sun shines I look for prominences, and if they are unusual I photograph them. The better ones I show at a BAA meeting each year.

Dick: Do you collaborate with other observers or work just for yourself?

Horace: Oh, just for myself. My observing program is strictly mine. Any friend interested is welcome to come and use or see the material. Incidentally, the inclement weather is why it's good to have microscopes — the hobby of using microscopes — for cloudy times.

Dick: What do you think of the fact that magazines have dozens of ads for ready-made telescopes? Is that good or bad?

Horace: It is very good for those people who just want a telescope but who don't have the confidence or skill to tackle making one. You get more fun if you make your own. Of course, there are many people who make telescopes for the sake of making them and never use them!

Dick: What is to you the ideal size for a telescope, or is bigger always better?

Horace: Most people say you don't gain much by going above 15", and a large telescope will have fewer nights of operation in less than perfect seeing, whereas, when a smaller instrument will still operate under these conditions.

Dick: Do you often stop down your 15.5" instrument?

Horace: When it's required. With mine it is merely stopping down with my iris control at the exit pupil of the system that stops down my aperture.

Dick: Do you use the camera obscura in your roof for other than looking at landscapes?

Horace: I have used it to look at the sun and planets when they are too low to be reached with the observatory instrument.

Dick: Does the heat from the roof interfere with seeing?

Horace: Only in the sunshine. At night I have had great views of the moon and planets and photographed them through the instrument.

Dick: That is a two-element objective, I believe, working at f/32?

Horace: That is right. By using special Chance Brothers glass at that focal ratio, I have brought four colors into focal plane coincidence resulting in practically no visible color.

At this point, the batteries in the tape recorder ran down, and the rest of the interview was lost to posterity.

On the Construction of Foamcore Telescope Parts

One of us (Rob) wanted to visit Australia to view the southern Milky Way and the Magellanic Clouds (and incidentally Halley's Comet) with as large a telescope as practical. We both had Odyssey-I 13" Dobsonians, and the trip seemed like a good excuse to build a new, light, portable telescope around the original optics. After long discussions, we decided to build a telescope using "foamcore" technology. Foamcore is made from a (typically) wooden box, or shell, around a piece of styrofoam. The assembly is held together with epoxy that also forms a stiffening matrix in the interstices of the foam.

The following is a step-by-step description of the construction of a piece of a telescope (the ground board of a Dobsonian mount) using our home-brewed foamcore technology. Our information came largely from the references on boat-building, but there should be enough information here to inspire ATMs to investigate this technology.

The idea is to manufacture a plastic bag (more a sandwich, really) to contain the structure as it's built from wood, foam, and epxoy, then to use a vacuum pump to evacuate the bag allowing atmospheric pressure to clamp it firmly together as the epoxy sets.

1

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1. Find place that will stay dry for 12 hours (more if it's cold), set up a flat surface, and sweep it clean. Grit on the surface can puncture the plastic bag, causing leaks.

2. Lay out a thick sheet of polyethylene that is much larger than twice the area of the work. Run a double bead of putty around the outside of half of it. This is the bottom half of the plastic bag (more a sandwich, really) containing the work. Bring in the tube from the pump, building plenty of putty up where it enters the nascent bag.

3. If there are any holes in the plastic, seal them with a dab of putty and a little piece of plastic.

4. Put down the bottom surface of the work, in this case the bottom panel of the ground board. Since the construction will be held together only by epoxy, it may be necessary to use pins (we used toothpicks) to align the pieces while the epoxy sets.

5. The epoxy is a two-part mixture that can be obtained from marine supply stores. You'll need resin and hardener in a ratio of 5:1. The easiest way to mix them is to purchase push-pumps from the epoxy supplier. These pumps eject a precise quantity on each stroke. You'll also want a plastic cup in which to mix the epoxy, a stick to stir it with, a little brush (10 cents at the hardware store) to apply it, and a 15-centimeter-square "spreader" made with a flat piece of plastic or metal. Cut little notches (2mm equilateral triangles work well) along one edge of the spreader so the "squeegeeing" action will leave raised beads of epoxy on the surface.

6. Epoxy is hard to remove from skin, so rub into your hands a liberal quantity of Jergens SBS 46 Protective Cream, available from suppliers that stock the epoxy. The cream repels the epoxy but washes off with water or automotive hand cleaner.

7. Mix up 50cc or so of epoxy and start assembling the workpiece. Apply epoxy to every internal surface. Use the brush on relatively small surfaces...

8. ...and use the plastic plate to spread the epoxy on large surfaces. The epoxy takes 30 minutes or so to begin setting, so work carefully — there's no rush.

9. Internal wooden bracing will add considerably to the stiffness and incompressibility of the finished piece, but little to its weight. Most of the

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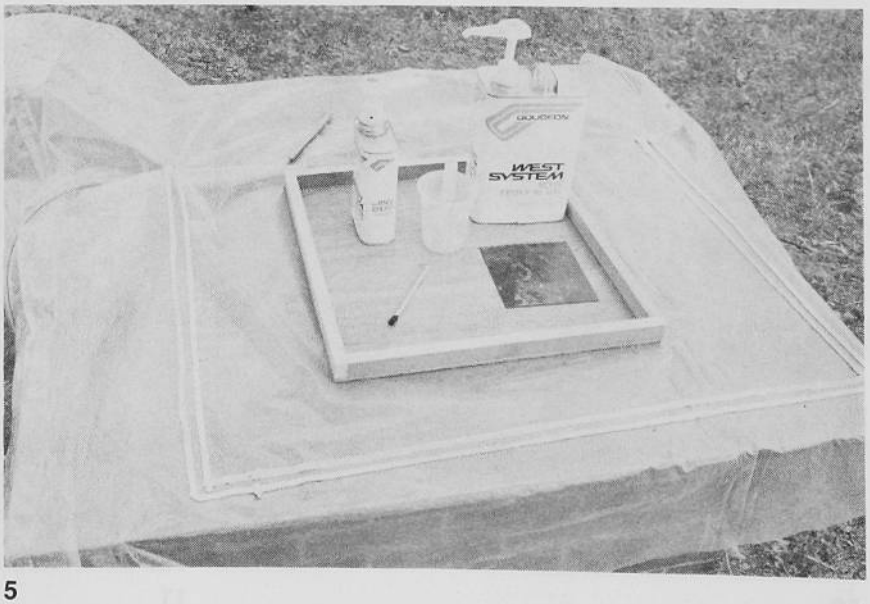

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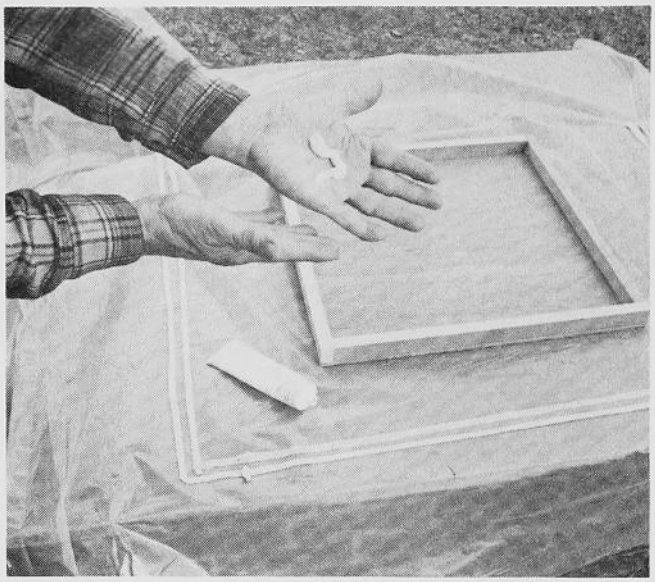

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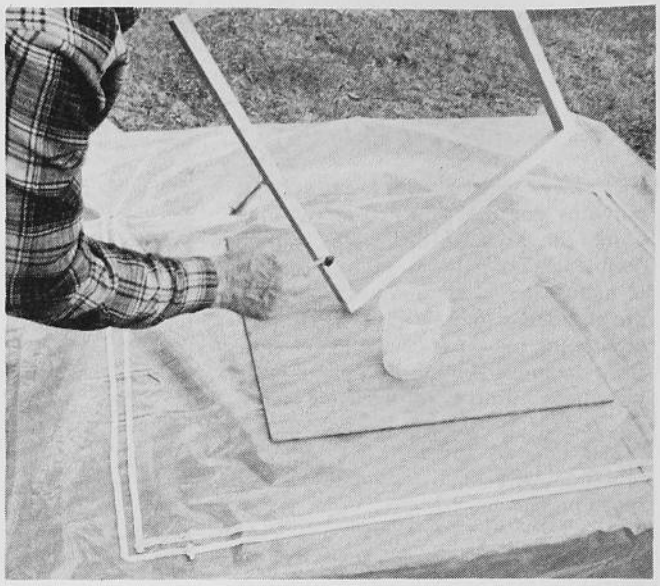

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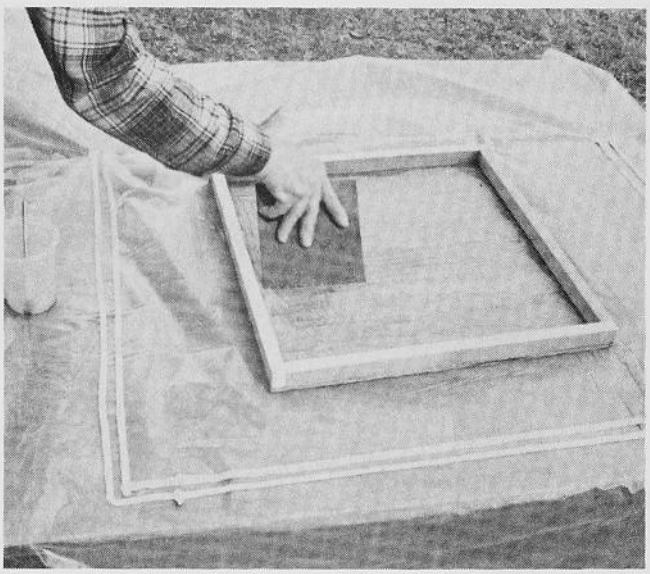

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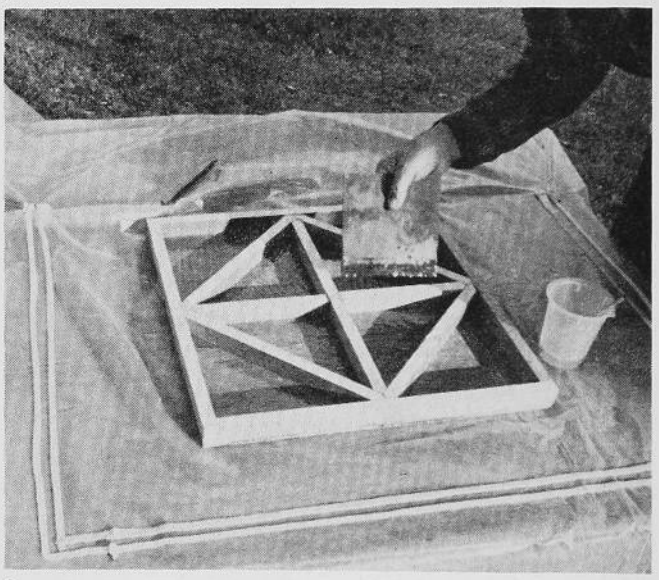

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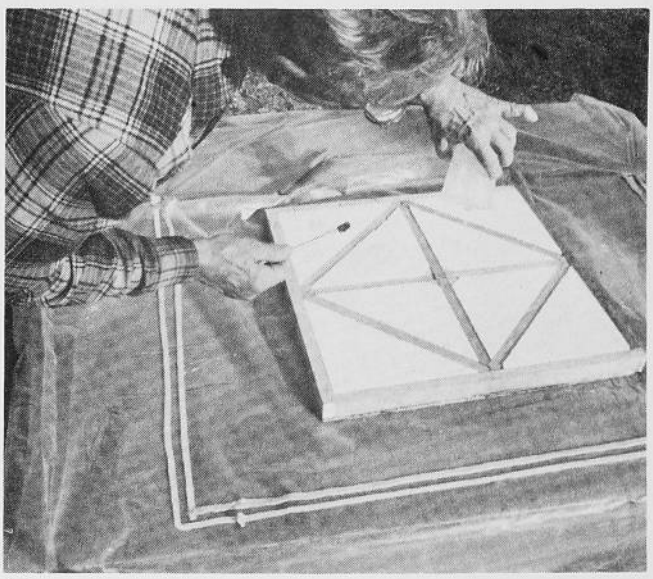

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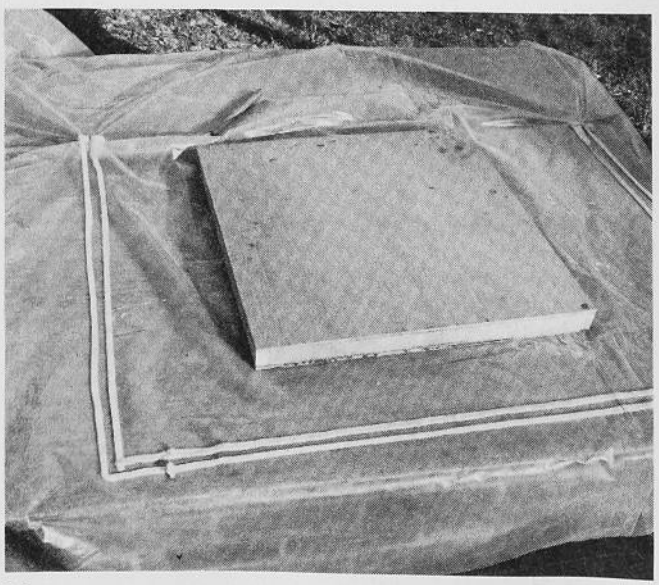

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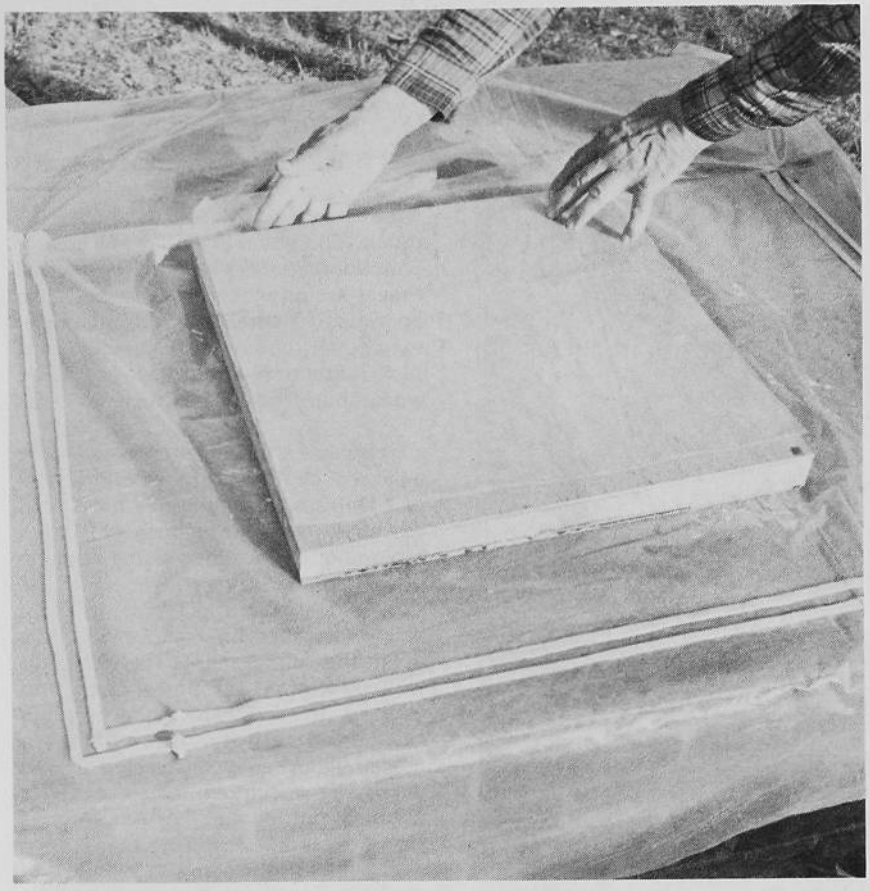

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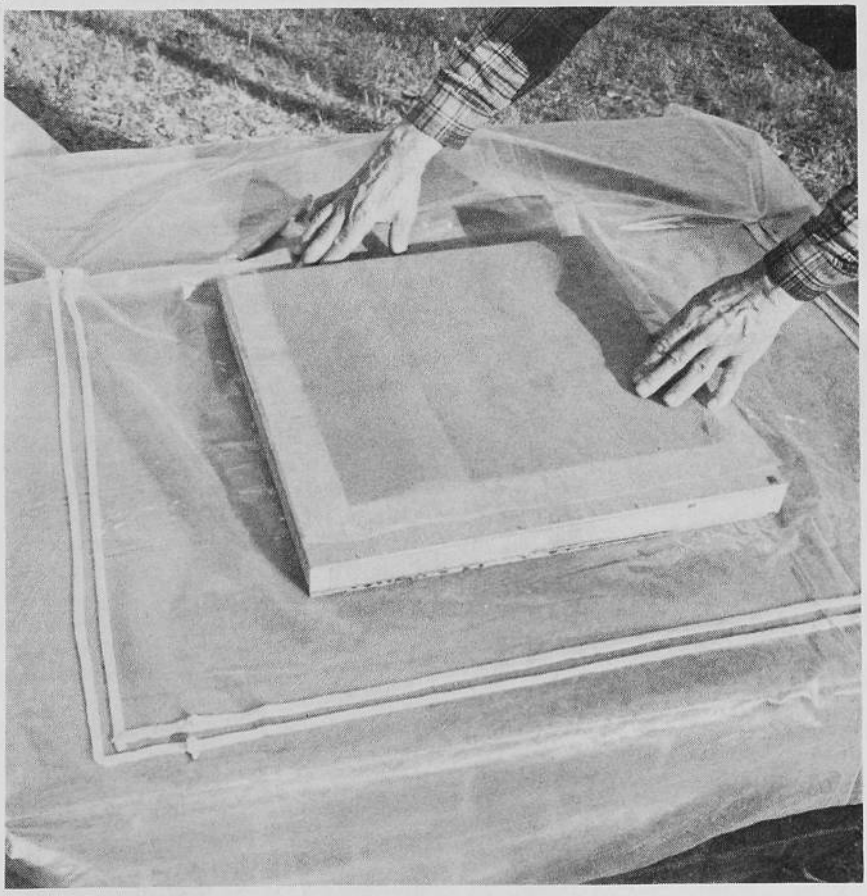

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internal volume will be simple styrofoam. This piece is the bottom plate of a Dobsonian mount, so the braces are laid out roughly to follow the track of the teflon support studs that support the weight around the azimuthal axis. The internal bracing forms only triangular spaces to maximize rigidity.

10. Insert the sheets of styrofoam into the center of the work. The foam should be slightly thicker than the final piece because it will compress when the vacuum is applied. It's hard to cut foam accurately, but we tried to get about 0.5mm per centimeter of thickness. Make sure all the flat surfaces have generous applications of epoxy.

11. When the top surface is applied...

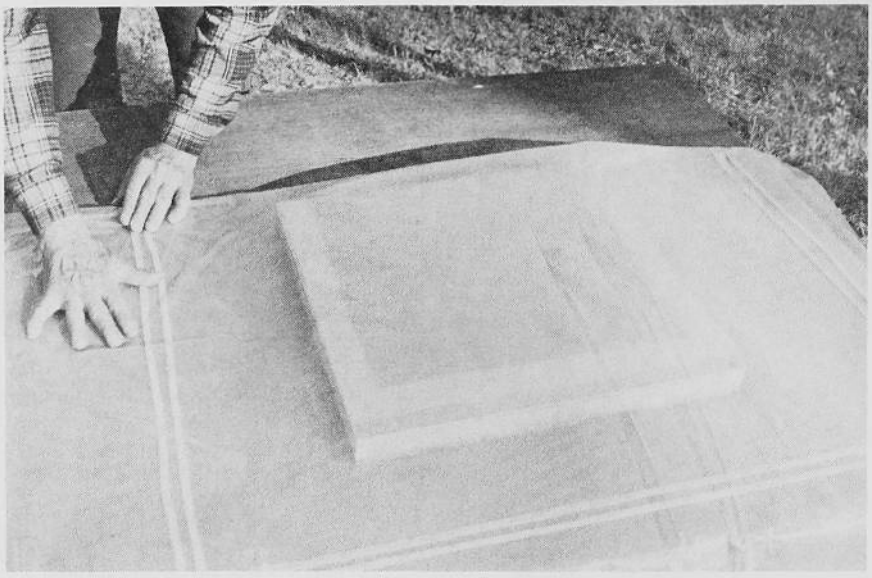
12. ...add a sheet of polyethylene...

13. ...to prevent the plastic window screen from sticking to the work due to epoxy sucked from the interior by the vacuum. The screen keeps an air gap, however small, between the work and the upper sheet of polyethylene, allowing air within the work to escape to the hose.

14. Fold over the plastic and make sure to get a tight seal between the pieces. Have a little putty handy to repair any leaks you discover when you start to pump (listen for them). It requires a little fussing to get a good seal all around, especially near the tube (here under Dave's left hand).

15. The vacuum pump doesn't have to be spectacular: we can only pump down to about 0.3 atmospheres. (Near the right edge of some of the pictures you can see a pressure gauge.) That means 0.7 atmospheres of pressure on the work, or, at 1kg per square cm per atmosphere, about 700 gm per square cm of external pressure. This piece was about 50 cm square, or 2500 square centimeters, so even with our modest vacuum pump the pressure is equivalent to resting a 1750 kg weight (about two tons) on the work. Our pump is from an IBM punched card reader. A suitable one can also be made from the compressor taken from an old household refrigerator.

16. The epoxy will cure in about 12 hours. The pump must work the whole time, so be sure you can rely on it, and that the hoses are properly clamped. (Actually, time to cure depends on



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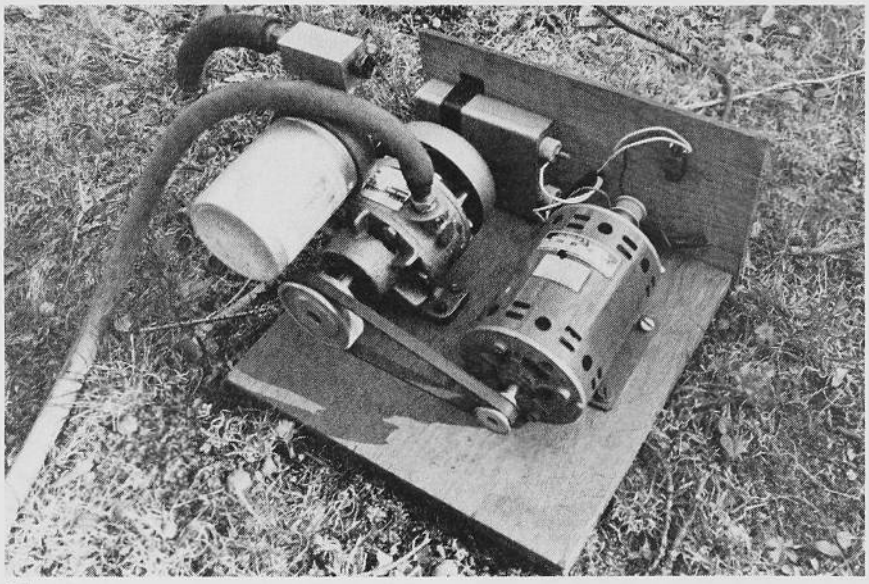

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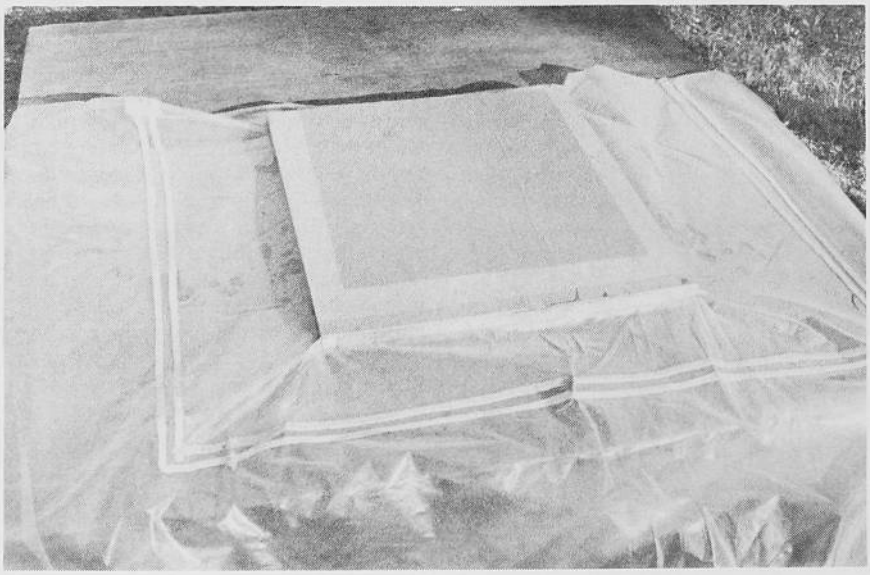

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temperature. It can take much longer when the ambient temperature is below the normal curing temperature of the epoxy.)

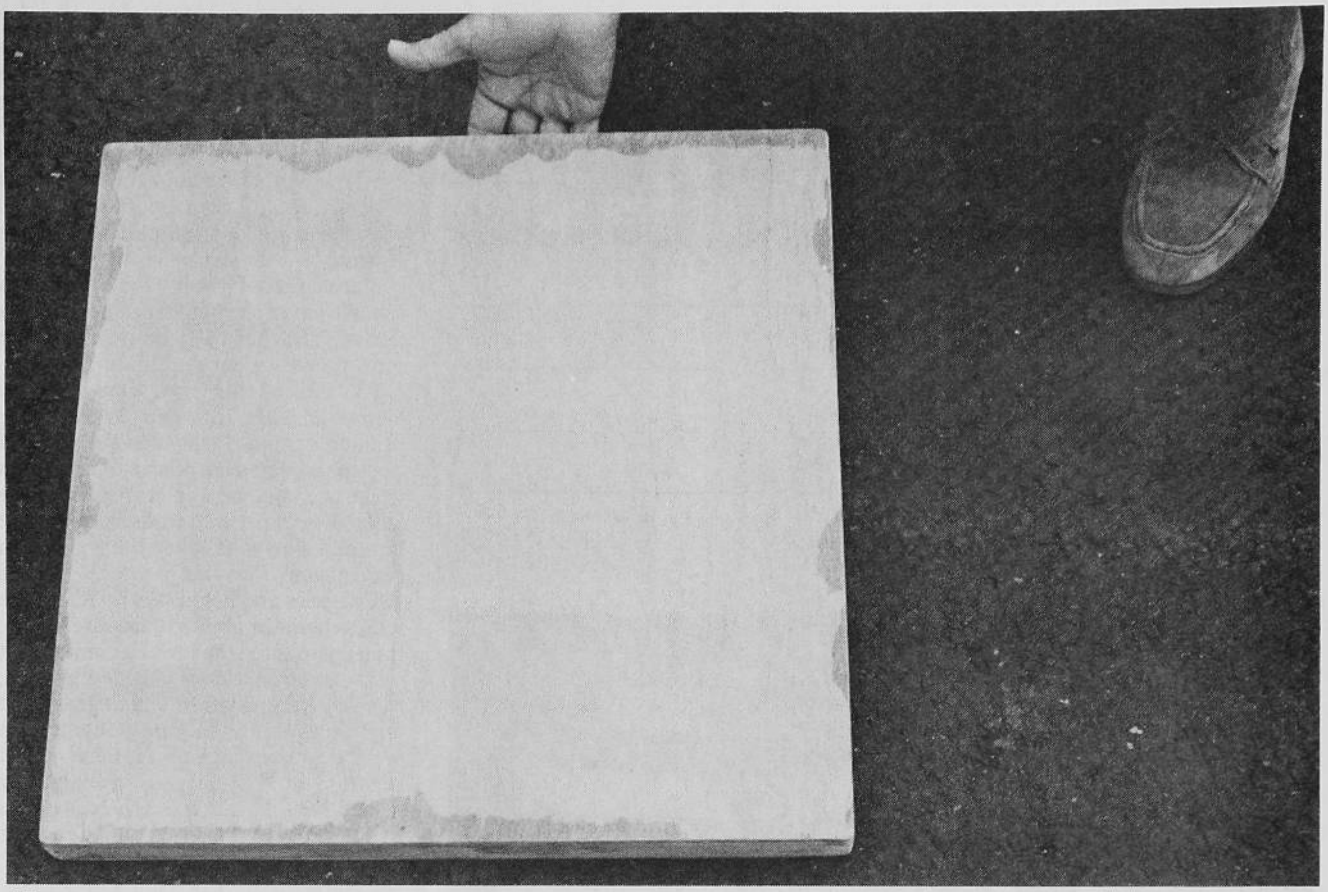
17. Here's the final piece; it weighs 3 kg. A piece of chipboard this volume would weigh 6.6 kg — over twice as much. The weight savings are greater with thinner pieces because the internal braces are unnecessary. The piece can be sealed by spreading a thin layer of epoxy over the surface using the plastic plate (without notches). Two coats give a nice shine, but one is sufficient to seal.

This piece is a simple replacement for a piece of chipboard — the bottom plate of a Dobsonian mount. We have used essentially the same technology to build tubes and tube sections, using a couple of crossed-grain layers of veneer for the skin and standard polystyrene foam inside, without internal bracing. To make the round shape, the veneer is wetted, wrapped around a form, and allowed to dry. The tube is then assembled around the form, a polyethylene bag is constructed around the whole assembly, and the air is pumped out of the bag, exactly as above.

The final picture shows Rob in the Australian outback after a long night's observing with the portable 13". The tube is made of seven foamcore pieces made around a cylindrical form. The bottom six pieces are each half a cylinder; two pieces join to make a cylindrical section of the tube. The top piece is a full cylinder that holds the diagonal and focusing tube. The entire tube, minus optics, weighs less than 10 kg, well under a third of the weight of the Odyssey tube that once housed the same optics. In fact, the entire telescope weighs less than just the tube of the Odyssey. The base is a conventional¾" plywood box that forms the crate for shipping the telescope as a large piece of luggage on the airplane.

In practice, the¾" plywood box (made in a rush as the departure date neared) didn't meet our stiffness criteria, which is why the photos above show us assembling part of a foamcore base. The pieces of the foamcore base are 1¼" thick, but they weigh less than¾" plywood. Since stiffness is proportional to the cube of the thickness, these foamcore pieces are almost five times stiffer than the plywood, and the final base (built after the trip) is impressively sturdy.

Rob Pike
Dave Hagelbarger
18 Elizabeth Street
Millington, NJ 07946



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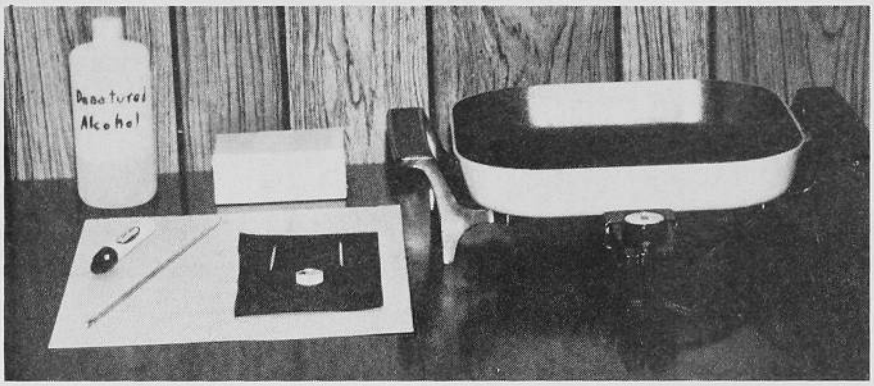
Cementing Achromatic Lenses

Materials needed to cement a lens: alcohol, a box to protect against drafts, marking pens, lens, toothpicks, a frying pan, and a thermometer.



Dropped your eyepiece? Banged your binocular against the car? Woe be to you if the lenses of the achromatic pair are separated! Guess you'll have to throw them away or send them to the manufacturer to be re-cemented. Wonder what that'll cost?

Actually, anyone can re-cement a separated pair of lenses using today's modern lens cements. For many years the most common cement was Canada Balsam. A thin film of this material between the lens elements bonded them into a single unit. Even though the cement did not match the index of the glasses used (the ideal situation), the layer of Balsam was so thin that the index differences could be ignored in most cases.

Today most lenses are bonded with an epoxy-type cement. Some epoxies use a catalyst that sets up the main material making up the cement. They can be tricky to work with, since careful measurement of the amounts of cement and catalyst is needed. In many cases you have very little working time before the bond becomes permanent, so the first attempt had better be right!

Fortunately there has been a new development in lens cements. The new cement comes as a liquid, and it sets only after exposure to ultraviolet light. There is no heat needed in the bonding cycle, which reduces the danger of especially in lenses that have a thin center flint element.

Separating Old Lenses

Suppose you have to separate an achromat. What should you try first? If it's an old lens, then the cement is probably Balsam, and heating will separate the elements. Generally a temperature between 135 and 175 degrees will do the job, and a hot plate can be used to heat it. You don't have a hot plate? Sure you do, you just don't recognize it as such. An electric frying pan is an excellent hot plate. I worked at an optical shop that used frying pans instead of expensive laboratory hot plates in many applications.

Besides the frying pan you'll need a pair of toothpicks (or, if the lens is heavy, two tongue depressors or similar pieces of wood), a thermometer, a black piece of paper, cleaning alcohol, and a small box to cover the lens when heating and to hold in the heat and protect against drafts of cold air.

Punch a small hole in the top of the box, off to one corner, and insert the thermometer half way down into the box. Place the box on the frying pan and slowly advance the temperature control until the temperature reaches and holds a steady 150 degrees. Mark the dial so you can reset this temperature in the future.

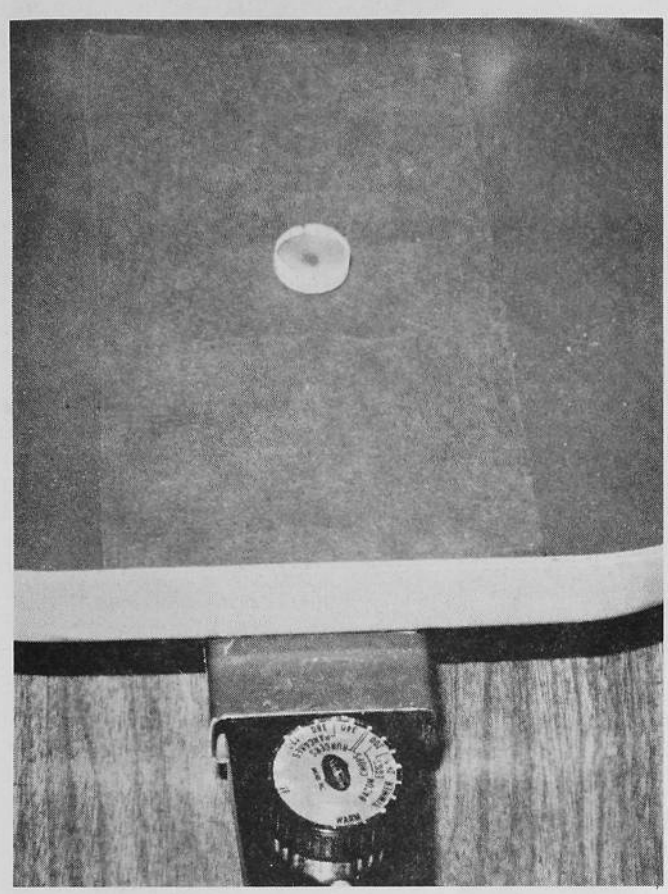
Place a piece of heavy black paper on the bottom of the pan to protect the lens surface and put the lens on the paper with the steep curve (crown side) up.

To assure that you can put the elements back together at the same orientation, place marks on the edges of the lenses with a marking pen, as shown in the accompanying pictures. Place the small box and thermometer over the lens and slowly advance the frying pan control until the temperature reaches 135 degrees and holds steady. Allow the lens to heat for about 10 minutes or so, then try to force the lens elements apart with the toothpicks. If they don't budge, raise the temperature 175 degrees and let it heat for 15 minutes, then try to separate them again. If they won't separate at 175 degrees, then epoxy cement was used to bond them and you will never get them apart by the process you just tried.

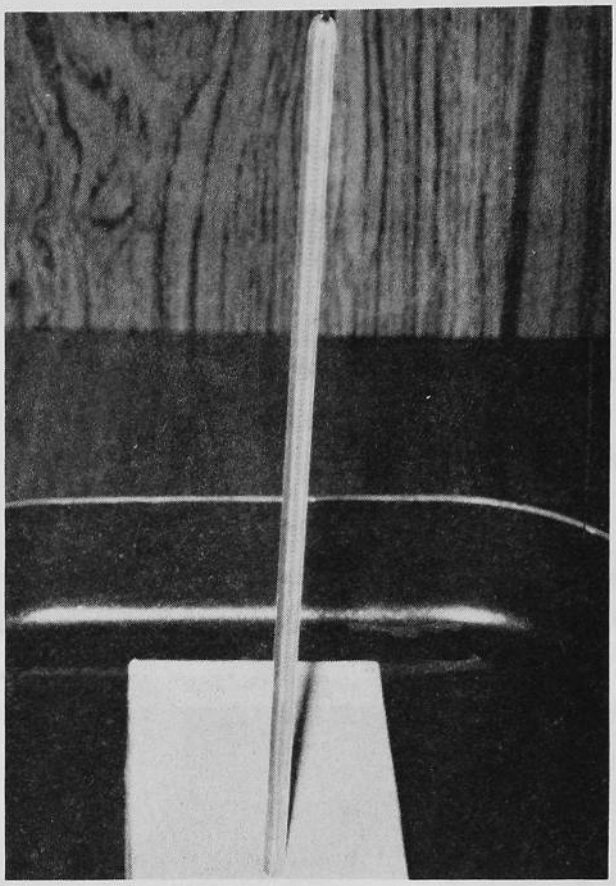
Separating Epoxied Lenses

Epoxy cements are hard to separate once set. I discovered this the hard way. I was working on a separated binocular objective that belonged to a vice-president of the company. While removing a few stray air bubbles I did not work fast enough,and the bond took place while the lenses were not centered on one another. Well, after the panic subsided a bit, I read the instructions. They suggested boiling the lens in peanut oil or heating it to 300°C in a vacuum oven. Luckily such an oven was available, and it saved the day. I held the lens at that temperature for about 20 minutes, then took it out and cooled it. The two lenses just fell apart in my hands since the cement had lost its volatiles in the vacuum and had become a harmless powder with no holding action. Needless to say, I took pains to work faster the second time and finished the job successfully.

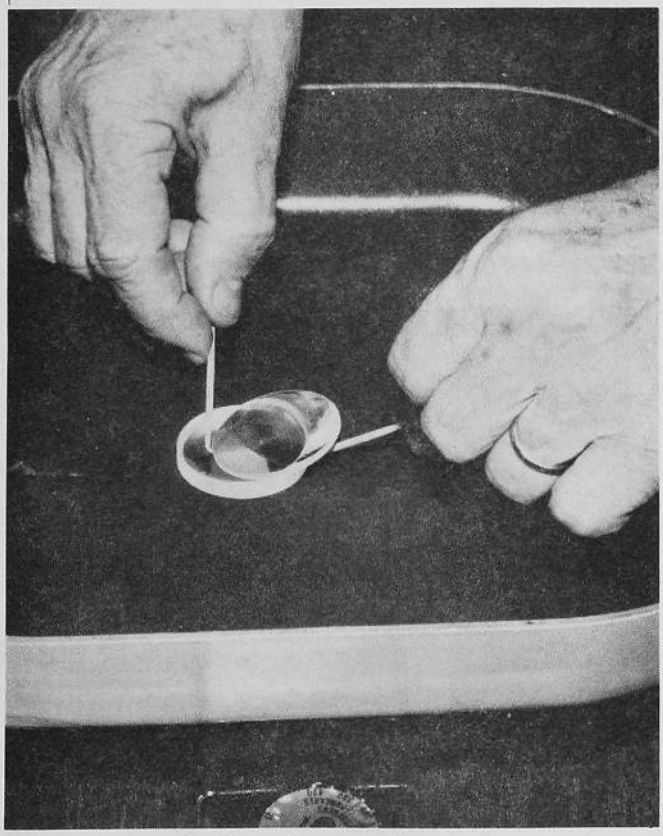
Heating the lenses in oil in temperatures up to 400° for 20 to 40 minutes and pressing on the edges with a tongue depressor will also separate them. It is possible to use peanut oil, vegetable oil, mineral oil, or even light motor oil. But be warned! At these temperatures, most oils give off fumes that can drive one out of a work place. Plenty of ventilation is needed when doing this. Let me put it this way, if you don't ventilate the area then one of three things will happen: 1)



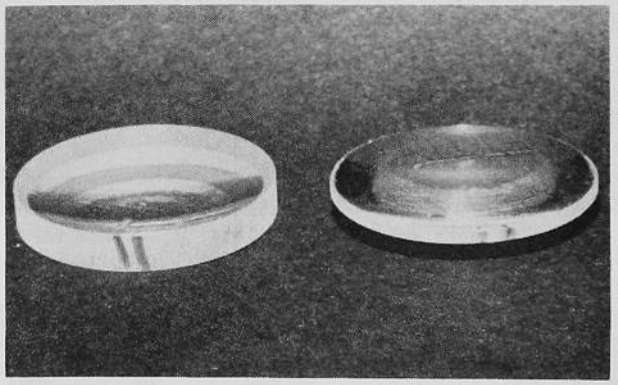
The lens to be separated sits in the frying pan on black paper.



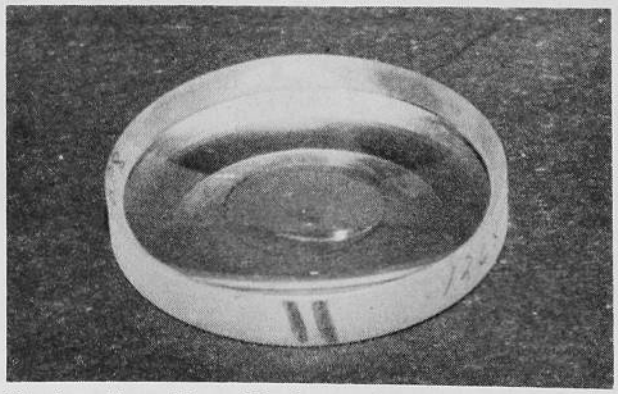
The thermometer is inserted in the box and used to set the temperature dial to desired range.



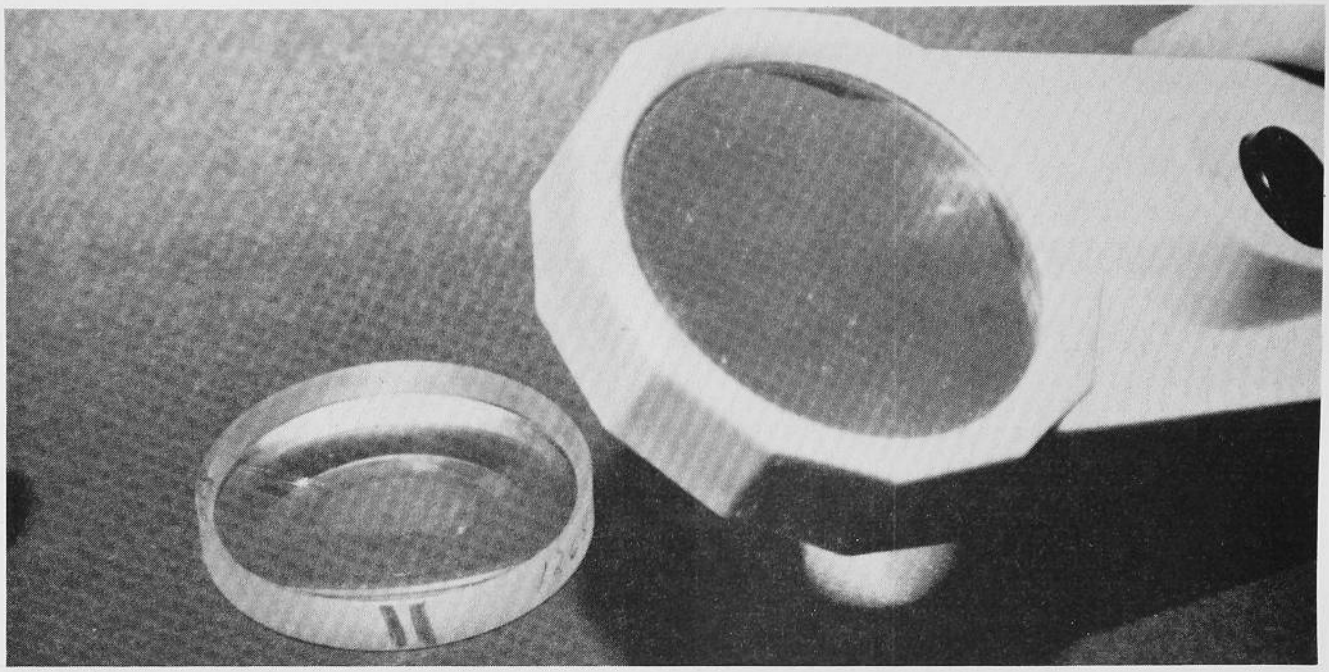
Gently separate the lens elements with toothpicks.



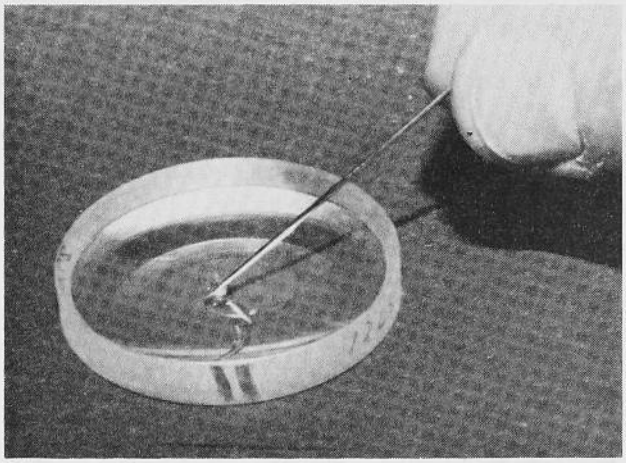
The separated lens elements showing old cement on the surfaces.



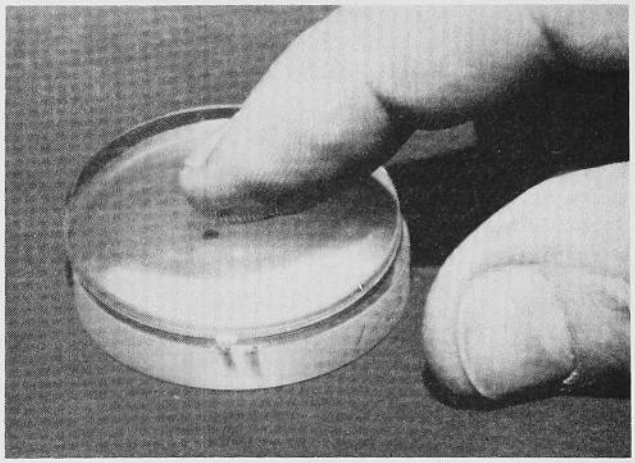
The cleaned lens with a puddle of cement in its center.



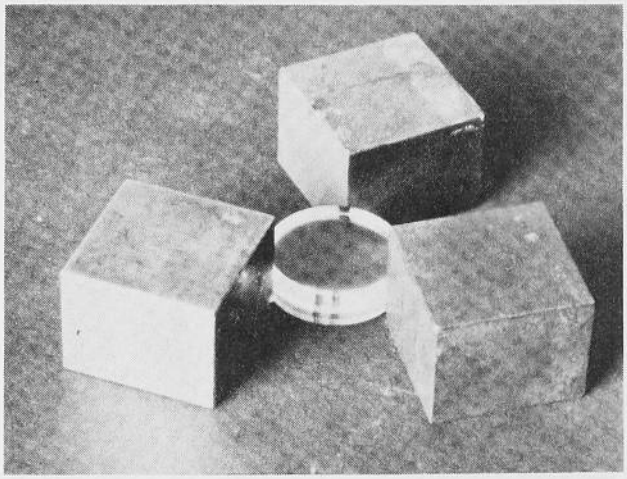
Looking for bubbles with light and magnifier.



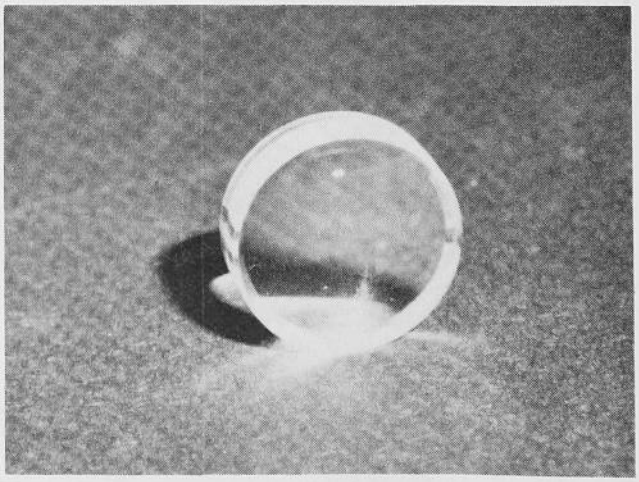
Using a straight pin, capture the bubbles and bring them to the edge of the puddle so they will be lost when the two lenses are mated.



Using gentle pressure, move the crown lens around to push any bubbles off the edge of the assembly.



Use blocks to center the lens before exposure to ultraviolet light.



The finished, re-cemented lens. Note alignment marks on the edge of the lenses!

Your wife will pack up and leave with the children for trying to asphyxiate them. 2) She will toss the oil and lens out the nearest window or door. 3) You will sleep alone in the spare bedroom for the next month! This method works but — to put it mildly — it stinks!

Once the lenses are separated they must be protected from thermal shock. Leave them on the hot plate with the box over them until the hot plate cools to room temperature. If you used oil, then put the lenses in a small closed box and allow them to cool slowly.

Many cemented lenses have the same curve on both sides of the crown lens (the convex one), so be sure to keep track of which side was in contact with the cement once they are separated. Since most modern lenses have anti-reflection coatings on the outer surfaces, you can examine the lens and put the uncoated surfaces together in final assembly.

After separating them, clean up the lenses with alcohol. If possible, use a reagent grade solvent. I have never tried it, but whiskey might work as a cleaning agent (and it won't cause double images later). Of course, you shouldn't scratch the lenses while cleaning them. Protect the outside coated surfaces and be willing to do plenty of soaking and gentle swabbing of both surfaces. Do not try to hurry the job!

Re-Cementing

The most popular lens cement today, and the one that's easiest to work with, is the ultraviolet sensitive type. This is what I recommend for the amateur.

The cement I'm most familiar with is Adhensive 61. It's made by Norland Products Inc., 695 Joyce Kilmer Blvd., P.O. Box 145, New Brunswick, New Jersey 08902, phone (201) 545-7828. A bottle of this cement costs about $10. At room temperature (70°) it should keep about 4 months, but keeping it refrigerated will greatly extend the life of the material. At McDonnell Douglas we used cement that had been refrigerated for 12 months with no problems.

We are now ready to re-cement the two lenses. One of the most important points is to be sure that you don't trap any small air bubbles between the two lenses when they are cemented. To help detect bubbles, place the lenses on a piece of black paper and shine a bright light on them. Bubbles highlighted in this way are easy to detect and eliminate.

After putting down the black paper, place the two lenses on it. Be sure the alignment marks you originally put on their edges are visible. Check that you have put the correct surface of the convex element up so the pair will be assembled properly.

How much cement should you use? The answer is to use as little as possible while still obtaining complete coverage of the surface. If you put on too little, you won't be able to squeeze the cement out the edges of the glass and will have to separate them and start over. If you put in too much, the cement will run out, make a mess of the edges, and probably get all over the rear surface of the flint, or bottom, glass. Although its viscosity won't match that of the cement exactly, make a trial run or two with mineral oil until you get a feel for the right amount.

The cement is put on the lens surface by touching the tip of the container to the surface and gently squeezing out the proper amount. Be sure that you don't stop squeezing and then continue; this produces bubbles. Squeeze it out all at once. For applying mineral oil, I have found dipping a long straight pin in the oil, then gently applying it to the lens surface transfers the oil to the surface.

After the cement or oil is applied, examine it for bubbles by shining a flashlight at an oblique angle across the lens surface. Look through a low power magnifier for bubbles. Bubbles around the edge of the puddle of cement will be pushed over the edge, so don't worry about them. Those in the middle should be brought to the edge. Insert the straight pin into the puddle of material and touch it to the bubble. The bubble will usually attach itself to the tip. Gently move the tip of the pin to the edge of the puddle dragging the bubble with it. When all noticeable bubbles are removed the two lenses can be mated.

Pick up the convex crown element, turn it over, and center it just above the flint one with the marks lined up. Now gently and slowly allow the lens to descend until the center of the crown just touches the puddle of the flint. Do this slowly or you can trap large air bubbles between the two pieces of glass. Slowly continue to lower the crown, pushing the puddle of material out toward the edge of the pair until the lens sits on the puddle without your having to support the crown lens.

The cement will probably not reach the edge of the glass initially, so gently apply pressure at the center of the top lens to make the puddle reach the edge and then squeeze out the excess material. Before going further take the light and magnifier and look for bubbles between the two surfaces just inside the lens edges. If you are fortunate, there will be none or perhaps just one or two.

To remove these bubbles, with gentle pressure oscillate the top lens out and over the edge of the bottom one. It will carry the bubbles along with it. As you bring the two glasses back together, the bubbles will be scraped off and lost. Continue until all bubbles are gone.

The layer of final cement should be very thin, so once the bubbles are gone, apply more pressure and squeeze out excess cement. If you've used the proper amount of cement, the excess will be small and the edge and bottom surface of the flint will remain fairly clean.

It is now necessary to center the lenses and fix the cement by exposure to ultraviolet light. Center the lenses pressing two machinist's "V" blocks against the edges of the lenses. If you don't have these, fasten down two blocks and butt the lenses against them. Bring up a third straight edge, as shown in the photographs, and touch it to the lens edges. If firm contact is made by all three, alignment is insured when the cement sets.

All that remains is to expose the assembly to a source of ultraviolet light. The cement manufacturer recommends two 15-watt fluorescent black lights at a distance of 3 inches, or a 274-watt G.E. Sunlamp at 18 inches. Now the beauty of this type of cement becomes apparent. With these lamps, you first give a precure exposure of 60 seconds with the black lights and 30 seconds with the sunlamp. After this step you can handle the assembled lens. Pick up the lenses and carefully clean the surfaces. Examine it carefully for any missed bubbles. Before the epoxy is cured, the lens can be separated easily and the job started again.

Clean the edges of the lenses. A single-edge razor blade works fine and keeps any solvent away from the edge of the lenses. If everything looks good, exposure is continued, 20 minutes for the black lights, 10 minutes for the Sunlamp in the case of the Sunlamp 10 minutes, to obtain a full cure. However, according to the manufacturer of the epoxy, complete aging of the epoxy takes three weeks. Before this time, avoid any temperature extremes or shock. The lens can be mounted and used when the full cure time has elapsed, and any further cleaning can safely be done.

If you are now holding a lens combination in your hands and it is still all in one piece (you haven't dropped it in your excitement) then congratulations — you are an "expert" lens cementer. Well, in any case, you can say you have successfully cemented one set of lenses together. And that is an accomplishment.

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Design and Construction of a Super Planetary T

The standard achromat doublet is far from satisfactory for critical lunar and planetary work because of significant color error in the wavelength range between C and F (red to blue). The color error is typically 0.06%, which cannot be improved because the limitation is imposed by the glasses available for the lens. The exception, of course, is calcium fluoride, a mineral crystal that can be combined with certain crown glasses to achieve doublets essentially free of secondary color. However, calcium fluoride is quite expensive in sizes larger than 4 inches and is comparatively hard to work.

Some observers, though, feel that achromats are sufficient for good planetary work. Is improvement really necessary? I think it is. One look through a well-corrected apochromatic triplet lens is usually enough to convince even a skeptic, especially when he sees lunar and planetary features with a crispness that is hard to believe.

In his landmark paper, "Planetary Telescopes" (JOSA, February 1963, p. 111), James G. Baker defined a high-resolution planetary lens as one that achieves 0.1-wave color correction in the C to F visual range, and has only small errors in the deep-red and violet. To see how close a well-corrected achromat comes to meeting Baker's requirement, I have calculated the performance of the Hastings achromat (*S&T*, March 1979, p. 294).

The Hastings lens is corrected for the yellow-green visual peak. The focus has been adjusted for the sharpest visual image. The amount of secondary color can be estimated by comparing the image diameters at the various wavelengths. Image diameters of 25μ (.001") or less are sharp and color-free. The lines in boldface indicate the normal correction range for lenses. The deep red and far violet were included to show the photographic capabilities of the two designs.

Achromatic Doublet 6.25" f/15 e.f.l. = 93.8"

Wavelength	Color	Focal point	OPD	Image μ
4047 h	U.V.	0.428	14.75	742.6
4348 g	violet	0.210	6.73	369.8
4861 F	**blue**	**0.049**	**1.37**	**89.9**
5461 e	**green**	**0.000**	**0.04**	**1.9**
5893 d	**yellow**	**0.005**	**0.08**	**5.6**
6563 C	**red**	**0.053**	**1.11**	**84.0**
7065 r	deep red	0.106	2.09	172.2

The above table shows that the yellow and green are in sharp focus, but that the red and blue waves are more than 1-wave out of focus. This is four times the Rayleigh limit, and these colors detract from, rather than add to the image contrast. The r, g, and h wavelengths are even further out of focus, but this does not detract from normal lunar and planetary work because the eye is not sensitive to these wavelengths. However, these wavelengths are important in photography, and this lens would require a heavy yellow filter to work effectively.

Triplet Apochromat Lens Design

Optical designers who want to design a fully-corrected apochromat usually begin by surveying the list of glasses for likely candidates. A good starting place is the Pg,F-Vd diagram, which is available from the major glassmakers. This chart is a plot of the nonlinearity of index over the C to g wavelengths for the various glasses offered. The glass chart from Ohara shows that most glasses lie close together along the Abbe line (defined as the line connecting K7 and F2 glasses, named after Ernst Abbe). The color error of any two glasses can be estimated by the following equation:

% chromatic error = (PgF1-PgF2)/(Vd2-Vd1) x 100%

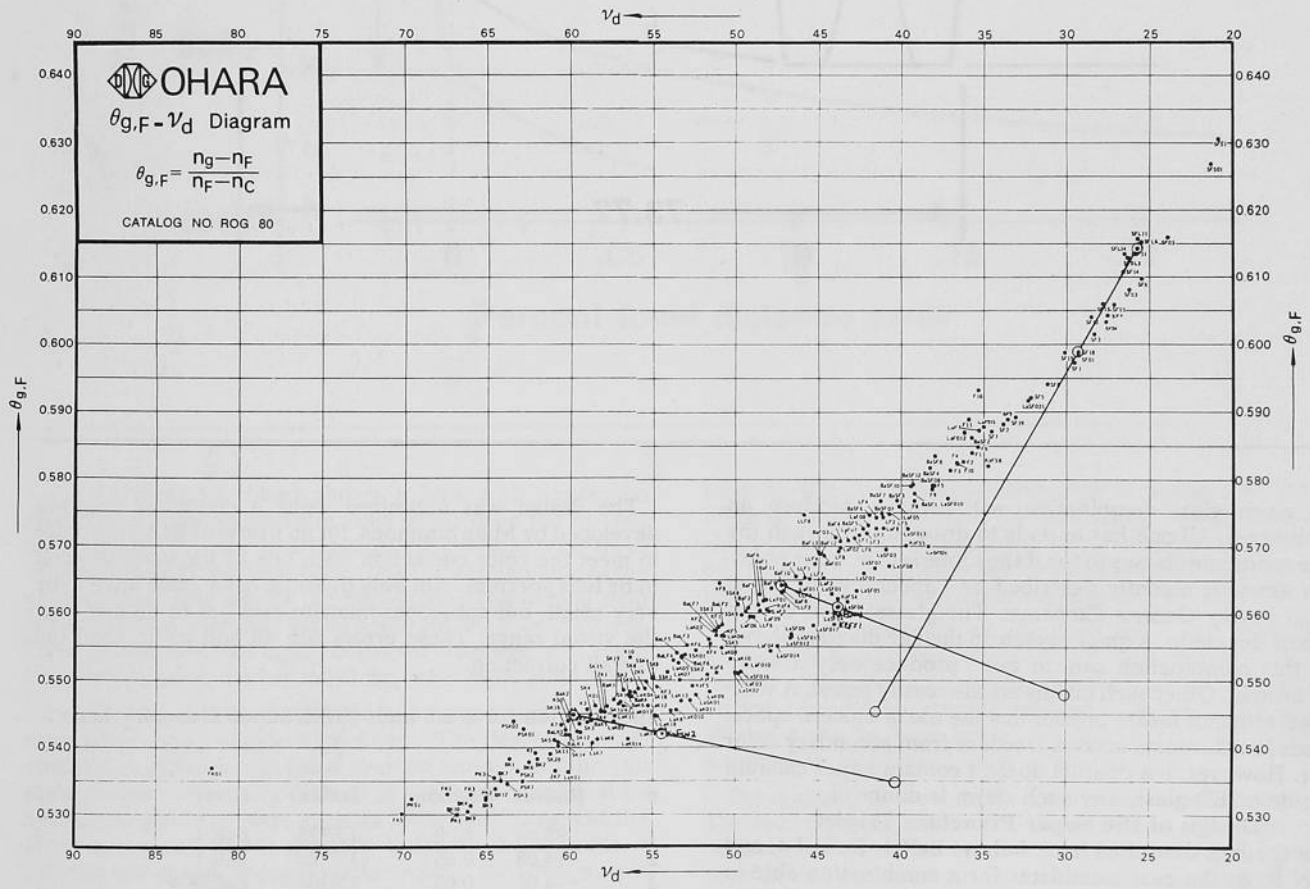
Since the slope of the line for any two glasses with significantly different Vd values is almost constant, the color error of any pair of crown and flint will be about the same.

Early investigators tried to combine glasses closely spaced in Vd such as BaK1 and KzF5 (Dense Barium Crown and Telescope Flint). This combination will produce a well color-corrected lens, but the extreme curvatures resulting from such closely spaced dispersions (Vd) make reasonable focal ratios impossible. What is needed are crowns in the extreme left hand region of the chart, or flints in the extreme right hand portion. The Ohara chart shows the calcium fluoride glass FK01 in the right place. This glass, combined with BK6 or ZK7, will indeed result in the superbly corrected Hexagon doublet as Mike Simmons described in *S&T* (July 1980, p. 64).

If one cannot use fluoride because of cost, one must "manufacture" a suitable flint glass. This is accomplished by combining a glass having normal dispersion with one having an abnormal dispersion (one that lies somewhat removed from the Abbe line) to produce a composite flint with the desired PgF and Vd. This synthesized flint can then be combined with an ordinary crown element to produce a color-corrected triplet.

The list of glasses that could be used is quite large, but certain practical criteria can be applied to limit this list. For myself, these criteria include cost, availability, and workability of the glass. Unfortunately, many glasses that are of interest to apochromat designers are extremely expensive.

elescope Objective



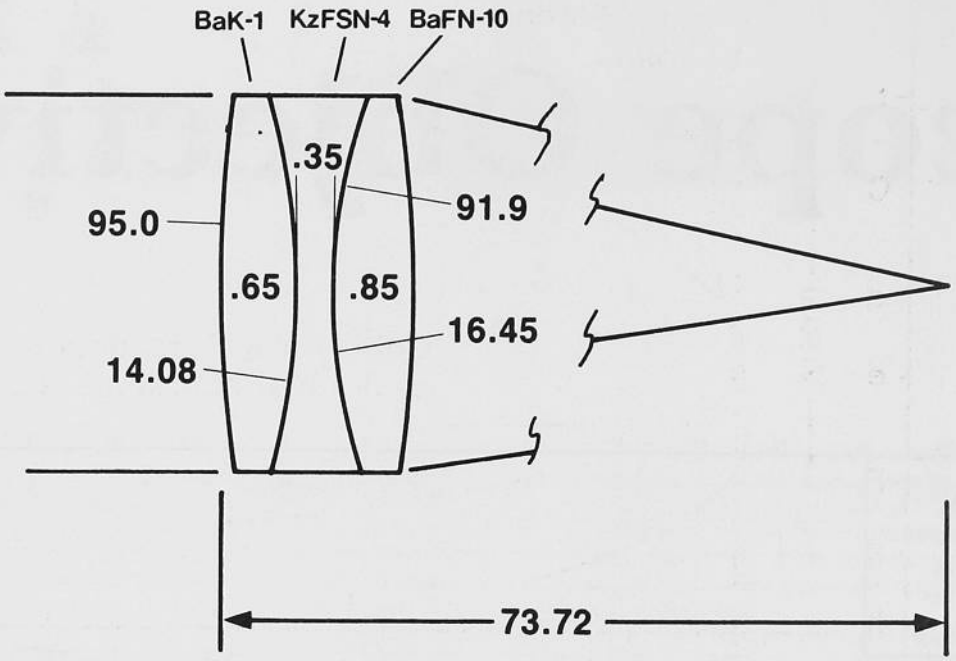
Cost and availability rule out all but about three dozen glasses, but this still leaves enough glasses for several hundred candidates.

To narrow the field further, I have limited myself to combinations that result in low internal powers (gentle curves), spherical aberration and coma corrected with only spherical surfaces, and an overall symmetrical design with negligible airgaps. Spherical surfaces can be made smoother than aspheric surfaces, and minimal airgaps allow for easier alignment of the critical interior surfaces.

There are several ways to synthesize a flint element. One can use a positive element of K5 and a negative element of KzFSN-2 to synthesize a flint with a dispersion of 40. It could be used with inexpensive crowns such as BK-7 or some of the FK or PK glasses.

A combination of BaFN-10 and KzFSN-4 produces a flint of Vd = 30 that can be combined with the dense barium crowns such as the BaK series. A combination of SF11 and SF18 was first suggested by Mike Simmons at Stellafane in 1984, and he has produced one in an 8-inch version. The Zeiss dense flint apochromat is similar and employs SF11 and SF4 as the active pair. Of course many other combinations are possible, but these three serve to illustrate the concept.

Weeding out the poor combinations requires a fairly sophisticated computer program. While there is too little room here to explain the intricacies of lens optimization, the glass chart allows one to quickly distinguish a good combination from a bad one. It will help even a beginner to determine



if a given glass combination will actually produce an apochromat. All one has to do is to draw lines through the three candidate glasses to see if they intersect at some point.

An amateur recently described an "apochromatic" lens design in *Sky Gazer's Exchange*. The glasses used do not support this claim. A quick sketch on the PgF diagram shows that this combination can, at best, produce only a semi-apochromat. Other such claims are also easily tested. A well-known refractor maker implies that the use of modern optical glasses in achromats insures freedom from secondary color error. However, if a doublet doesn't contain either calcium fluoride or ED glass, any such claim is doubtful.

Design of the Super Planetary Triplet

For the lens described here, I chose BaK-1, KzFSN-4, and BaFN-10 as the best candidates for a combination able to achieve the 0.1-wave criterion. These glasses are relatively inexpensive, very homogenous, and available from a variety of sources.

It is extremely important to get homogeneous glass for a triplet. The relatively high internal powers of an apochromat amplify variations in index, and this can ruin an otherwise color-corrected image. The glass must be at least three times more homogeneous than that required in a doublet.

I use only Schott precision annealed "P" quality (or schlieren grade) glass. I have had too many problems with ordinary "A" and "B" grade glasses to trust these grades. Ideally, the index variation throughout the blank should be less than $\pm 5 \times 10^{-6}$ nd. Glass of this type is available from Schott in Duryea, Pennsylvania, and can also be ordered from Glass Fab in Rochester, New York.

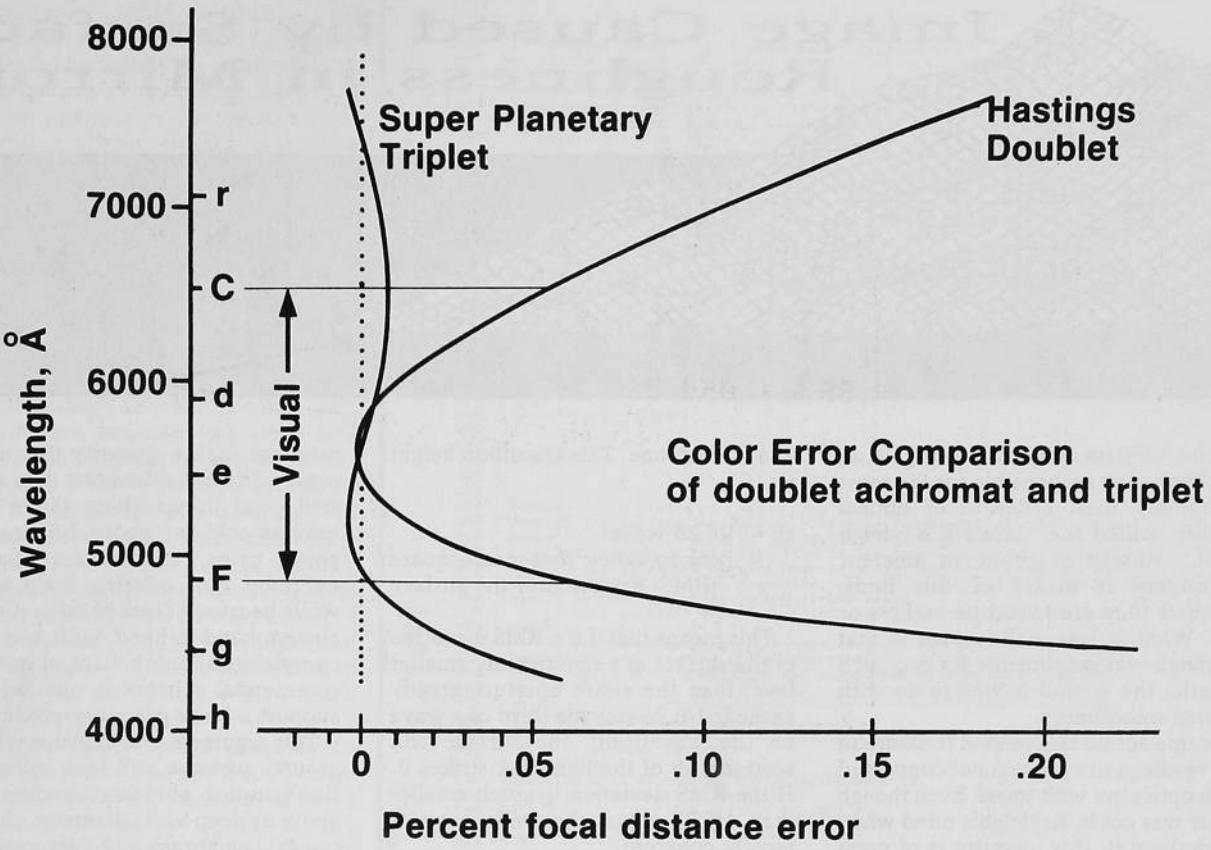
The design was optimized using a computer program developed by Mike Simmons, for an f/ratio of f/12.5. In order to meet the color correction goal, one of the variables had to be lens aperture. Not only does the color error have to be very small, but spherochromatism also has to be low over the visual range. These errors can all add up to spoil the overall correction.

Specification for a 5.8-inch f/12.5 Super Planetary Lens:

#	Radius	Position	Index	Glass
1	95.00	0.00	1.5725	BaK-1
2	−14.08	0.65	1.5725	BaK-1
3	−14.08	0.65	1.6134	KzFSN-4
4	16.45	0.90	1.6134	KzFSN-4
5	16.45	0.90	1.6700	BaFN-10
6	−91.90	1.75	1.6700	BaFN-10

Optical Performance:

Wavelength	Color	Focal point	OPD	Image μ
4047	U.V.	0.136	5.18	267.5
4358	violet	0.033	1.44	103.3
4861	**blue**	**0.003**	**0.10**	**22.1**
5461	**green**	**0.000**	**0.10**	**4.7**
5893	**yellow**	**0.005**	**0.09**	**4.6**
6563	**red**	**0.004**	**0.07**	**7.4**
7065	deep red	0.002	0.07	17.0



The performance chart shows a lens with almost no variation of focal length from 7065 in the deep red to 4861 in the blue. This lens is a classical apochromat with three zero crossings of the focal point: one in deep red, one in the yellow-green, and one in the blue-green. The optical path difference over the entire visual spectrum is 0.1-wave or less. Compare that with the highly-corrected achromat, and you'll find the achromat has ten to fifteen times more color error.

I have made lenses of this type and have tested them for color error using interference filters. The design displays virtually no difference in focus over the visual spectrum and shows bright white Airy discs. The violet error can just be seen on bright blue stars such as Sirius and Vega. On the Moon the color error is virtually invisible. Even Venus, a difficult test object, appears white without the usual purple glow. The extended red correction is really important for the red plant Mars. Although I am not a skilled observer, I have observed the recent close approach of Mars with this objective, and surface detail is so sharply defined that even I have seen a tremendous amount of detail. Jupiter, of course, presents the best show, with its multitude of cloud belts and storms.

This lens can be scaled up to 6- and 7-inch sizes. For a 6-inch aperture use an f/13 focal ratio; a 7-inch lens should use f/15 for the best results. The lens can be airspaced using a thin foil space (.002″). The lens elements should be mag-fluoride coated to prevent discoloration due to atmospheric attack. KzFSN-4 glass is easily workable but requires protection from dewing. Coatings will also raise the contrast by lowering the internal reflections. Glasses can be sent to Evaporated Metal Films in Ithaca, New York, for AR coating. The glasses can also be oiled with triply-filtered 200 cp Dow-Corning silicon oil. A few drops between the three elements eliminates all internal reflections and seals the sensitive Kz glass.

The triplet elements are worked the same way any achromatic lens elements would be. This design is quite tolerant of thickness variation, so there is no point in being critical here, but an accurate control of the radii is a must. Wedge must be kept below 0.3 mil (.0003″) to prevent astigmatism and lateral color error.

The design is sensitive to variation in index and dispersion. The radii must be adjusted to the melt data, otherwise the color correction will be no better than an achromat. Each lens must be run on the computer for the optimum design. If no computer program is available, the lens can be built to the above specifications and tested with interference filters. The two outer surfaces can then be re-ground to bring the color in. Color adjustments cannot be made by varying the airgaps because spherical aberration and coma change much faster than chromatic aberration in this design.

Since the design is coma-free, a fancy push-pull cell is not necessary. If the cell and tube ends are cut off square, the objective will show a perfect stellar image.

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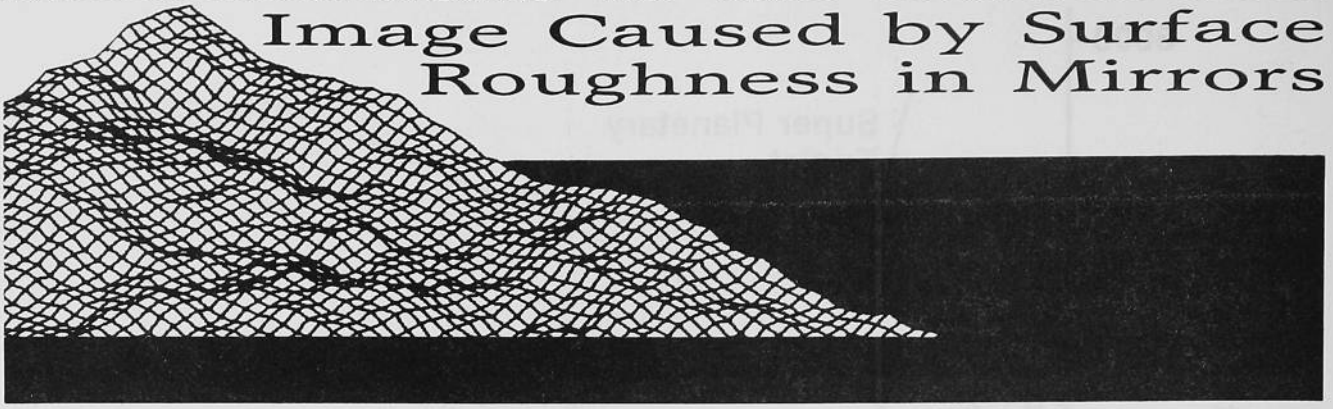
■

Modifications to the Diffraction Image Caused by Surface Roughness in Mirrors



John William Strutt, the third Baron Rayleigh, was responsible for the most commonly used criterion of optical quality, called the "¼-wave Rayleigh limit." Almost everyone in amateur astronomy is aware of this limit, whether they are telescope makers or not. What is less well known is that Rayleigh was responsible for *two* such criteria, the second having to do with optical smoothness.

I came across this second measure in my readings in a context not connected with optics but with *sound*. Even though sonar was not in Rayleigh's mind when he derived it, this quantity is of great interest to sonar engineers because it describes how rough the sea surface becomes. Sound is, of course, just a wave, so that what applies to sound can often be applied to light. Acoustics shares much of the same formalism and terminology with light. In fact, much of what we use in the "scalar approximation" to explain the behavior of light is an exact theory in the scalar waves of acoustics.

The statement of Rayleigh's other criterion begins with defining something called the Rayleigh parameter, "P":

if P = k*H*cos(angle of incidence),

where:

k = wave number = 2*pi/y
(y = wavelength)

H = RMS deviation of surface (peak-to-valley)

cos(angle of incidence) = approx 1
(normal incidence)

then:

P ⟨⟨ 1, means the roughness is small, and
P ⟩⟩ 1, means the roughness is large.

We may select P = 1 to be the transition region from a rough surface to a smooth one. This transition height is:

H = 1/6.28 wave
= peak-to-valley root-mean-square (RMS) deviation of the surface

This means that if the RMS deviation of the surface at a significantly smaller level than the entire aperture greatly exceeds 1/6.28 wave (a third of a wave on the wavefront), the surface will scatter a lot of the light that strikes it. If the RMS deviation is much smaller than 1/6.28 wave, the wave remains largely coherent.

Please remember, this is a criterion of smoothness — it's not meant to be applied to the overall figure of the mirror. It is meant more as a quantity to explain what is meant by "dog biscuit," or "primary ripple" and "micro-ripple," or even as a measure of the quality of the polish. This allows us to discriminate between "okay" mirrors and really excellent ones — the kind of optics you may have run into only once or twice in your life. You know the ones I mean. After a brief look in the eyepiece, you put your hand to your forehead and say quietly, "I've been wasting my time."

This calculation (H = 1/6.28 wave) has been done for a marginal or transitional mirror. It represents a ⅓-wave wavefront error and really wouldn't describe a decent mirror. What if we want a good one? The inequality above gives us considerable latitude for selection. Let's assume that "1/10" is much, much less than "1" (a change of an order of magnitude). Then the calculation of H becomes about 1/60th wave. Several years ago I came across a firm that manufactured quality optics. They guaranteed peak-to-valley RMS deviations no more than 1/40th wave. By this measure, we would call such optics smooth, or getting there. I remember thinking at the time that the mere fact that the makers thought to measure such a quantity (the mirrors came with individual test data sheets) said good things about them. These mirrors sold for about 2.5 times the going price, so the manufacturer naturally quit offering them after a while because of lack of sales. (Coupled almost hand-in-hand with our bitter complaints about the lack of quality of commercial mirrors is our failure to support a truly premium product.)

This argument also explains why fine ground surfaces still look milky. If a fine-grinding abrasive removes chips about as deep as its diameter, then the typical last abrasive (3 micrometers) is still digging holes about 6 wavelengtths deep, well above the 1.6 wavelengths that satisfies a P = 10 roughness condition that we might choose. Indeed, the only reasons that such surfaces appear quasi-smooth is probably because the abrasive quickly breaks down smaller than 3 microns in size and semi-polishes the surfaces.

Incidently, the old optical shop test of looking at the filament of a light bulb at an increasing incident angle (Texereau, 1984, pg. 45) has its roots in the sine term of the expression for P above. As the angle approaches 90 degrees (and the cosine gets small), arbitrarily rough surfaces will attain the smoothness condition and specularly reflect. The angle at which the onset of specular reflection occurs can be used to calculate the size of the holes being dug by the abrasive (don't expect much accuracy, though). The red appearance of the filament at the angle where it first appears is caused by the longer wavelength of red satisfying the smoothness condition first.

I have written a computer program to display mirror roughness and to calculate the resultant peak-to-valley RMS deviation (twice the RMS deviation from the average value of the height). You can get an idea of their relative roughness by looking at the printouts of what can be considered

smooth (RMS = 0.016 = 1/60 wave), "transitional" (RMS = 0.16 = 1/6 wave), and "rough" (RMS = 1.6 waves). Although I have used the relatively new mathematical technique of fractals, I have no justification for using fractals for this problem. I just wanted a technique that would allow me to inject some randomness into the situation.

My use of fractals offered me the hope of doing a successful job of modeling for several reasons. First, a fractal-generated curve is "self-similar," it looks about the same at several magnifications, and I believe a mirror's surface would have this property over a limited range of scale. Second, such curves have *localized correlation* (my term; I don't know if there is an official one). One point is strongly correlated with the amplitude of a nearby point, less well correlated with a point a little farther away, and only weakly correlated with a distant point. This is another property that I would expect of optical surfaces. (lest anyone think that I am an expert on the mathematics of fractals, you now know what I know about them!)

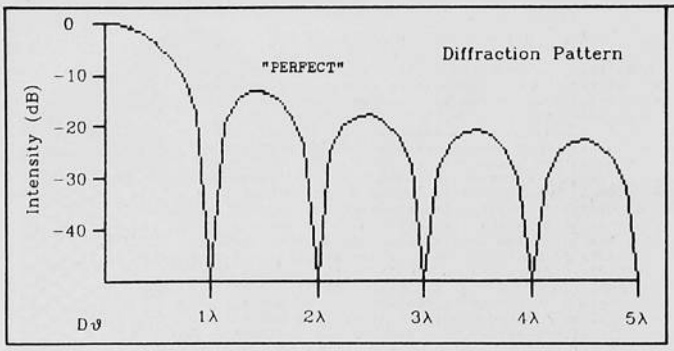
Primary ripple would probably be better modeled if I added a component of a sine function because it has a periodicity roughly equal to the polishing tool spacing. I have tried to add a quasi-periodicity by starting the fractal algorithm off with a certain number of regions (either 8, 16, or 4). These are then broken up by the fractal algorithm. I believe that the net effect models primary ripple well, as comparison with figures 41A and 41B of Texereau shows (incidently, these figures are mislabeled as being examples of micro-ripple — no doubt an editorial mixup — even though the text on page 87 says otherwise). In particular, my model displays the tendency to skip an oscillation or have the maximum in a different location that resembles the action in the real world.

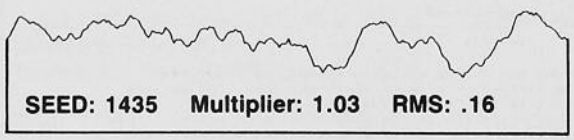
You will note that the program draws an enclosure below the rough surface. I don't want this to be taken literally as representing a mirror disk (I've been deliberately vague as to what is measured along this axis). This surface can be seen to be any *portion* of a mirror disk, and if we take the horizontal direction as being about ½", we see that we can take this as a model of micro-ripple too. I'll let you judge how well this works as a representation of micro-ripple by comparison with figures 29D and 41C of Texereau, but I think it works adequately.

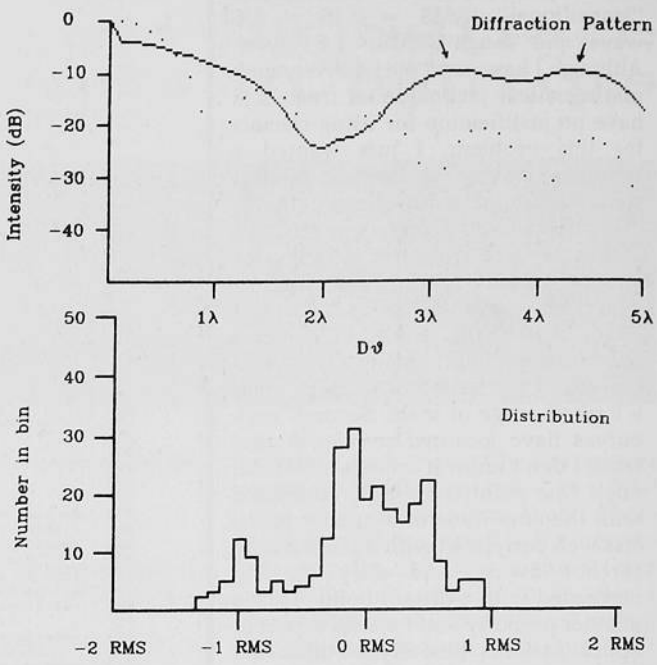
"What," you might ask, "is the bad effect of primary ripple only 1/20 of a wave length high [fig. 41A in Texereau] on a mirror with overall figure, say,

```
10 '
20 '          F R A C T A L   M I R R O R   M O D E L I N G
30 '
40 '      Fractal modeling is a powerful tool to generate "controlled
50 ' but random" structures.  While there is no reason to ASSUME that
60 ' mirrors are successfully described by the model described below,
70 ' we have to select something to work with.  I have used the
80 ' "mountain building" algorithm (in a severely abbreviated form)
90 ' that is reputed to have been used in several motion pictures
100 ' to generate the animation sequences.
110 '      A version of this algorithm also appeared in PC Magazine, MAY
120 ' 28/1985, where it was used to model mountains again. That version
130 ' was complicated by using variable length segments, so that the author
140 ' was required to manufacture a stack to properly do the recursion.
150 ' By using fixed, evenly spaced initial elements, and conveniently
160 ' spacing the elements to be powers of 2, I managed to avoid much of
170 ' the difficulty he encountered.
180 '      The model basically breaks up a surface into line segments. Say
190 ' we have points A and B separated by distance dx. During a single
200 ' iteration we are allowed to move point C midway between A and B
210 ' perpendicular to line segment AB by a distance dx*random**roughness
220 ' parameter. During the next iteration we are forced to consider twice
230 ' the number of elements, taking as line segments AC" and C"B.
240 ' The roughness parameter is usually between 0 and 2.
250 '
260 '          --                    C"
270 '          |                    / | \
280 ' dx*ran*rough*scale             /  |  \
290 '          |                   /   |   \
300 '          --                 A----C----B
310 '
320 '                             |--- dx --|
330 '
340 ' Because dx is divided by two during each iteration, the power to
350 ' distort the surface is limited -- after a few iterations, the surface
360 ' seems to "freeze."  This is the "controlled randomness."
370 '      One feature of this algorithm is its independence of scale. If you
380 ' look at a plot with a large number of iterations at two scales, both
390 ' a long way from the last iteration, and you lack other information, you
400 ' really cannot tell which is the larger scale.
410 '      I have included some "mountain" data at the end, for the user"s
420 ' entertainment.
430 '     Because this program is so heavily graphics oriented, there has
440 ' been no effort to write it in generic BASIC. It is written for the
450 ' IBM-PC using BASIC's equal to and beyond BASICA 2 or Cartridge BASIC
460 ' in the PCjr.
470 '-------------------------------------------------------------------------
480  DIM Y(256),YD(256), PLOT(40)
490 WIDTH 80:CLS: LOCATE 5,1: PRINT "A fractal description of a mirror."
500 PRINT "    by Dick Suiter"
510 PI = 3.141593
520 'FOLLOWING DATA IS ENOUGH TO INITIALIZE NR = 16,
530 'TO AN INITIAL CONDITION OF "FLAT."
540  DATA 1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
550  DATA 1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0
560 PRINT
570 PRINT "    AVAILABLE OPTIONS"
590 PRINT " 1 -- 8  regions, 5 iterations"
600 PRINT " 2 -- 16 regions, 4 iterations"
610 PRINT " 3 -- 4  regions, 6 iterations"
620 INPUT " PICK ONE [1 defaults]--> ";TEMP$
640     IF TEMP$ = "1" THEN NR=8: NITER=5: GOTO 720
650     IF TEMP$ = "2" THEN NR=16:NITER=4: GOTO 720
660     IF TEMP$ = "3" THEN NR=4: NITER=6: GOTO 720
670     IF TEMP$ = ""  THEN NR=8: NITER=5: GOTO 720
680 PRINT "Eh?": GOTO 620
690       ' NR AND NITER ARE NATURAL UNITS TO BREAK
700       ' THE PLOT UP INTO 256 UNITS: 8*(2^5)
710       ' OTHERS ARE 4*(2^6), 16*(2^4)
720  INDEX = 0
730  SUM   = 0
740  SUM2  = 0
750 NSR = NR
760  FOR I = 0 TO 256 STEP 256/NR
770    READ Y(I)
780    INDEX = INDEX + 1           'THESE THREE STATEMENTS INITALIZE
790    SUM   = SUM + Y(I)          'VALUES NOT COVERED IN THE FOR-NEXT
800    SUM2  = SUM2 + Y(I)*Y(I)    'LOOPS BELOW
810  NEXT I
820 '
830 '
840 IFLAG=0
850 PRINT:INPUT "Do you want Golden Software plot of mirror surface [y or n]";Q$

860 PRINT:INPUT "Do you want a distribution plot [y or n]";QD$
870 IF Q$=""  THEN Q$="N"
880 IF QD$="" THEN QD$="N"
890 IF Q$="y" OR Q$="Y" THEN IFLAG=1
900 PRINT
910 INPUT "Random seed (any number)"; SEED
920 RANDOMIZE SEED  'DIDN"T AUTOMATE THIS ON PURPOSE -- REPEATABILITY
930 INPUT "Roughness parameter  (usually 0 to 2)";VR
940 '
950 '
960   SCREEN 1: CLS: WINDOW (-20,0)-(300,3):KEY OFF
970 PRINT "Seed:";SEED,"Rand. Mult:";VR
980   LINE (0,1) - (0,.5)
990   LINE (0,.5) - (256,.5)
1000   LINE (256,.5) - (256,1)
1010   LINE (250,1.5) - (250,2.5)
1020   LINE (245,1.5) - (255,1.5)
1030   LINE (245,2.5) - (255,2.5)
1040 '
1050  PRINT "       MEAN  ";"     RMS"
1060   FOR ITER=1 TO NITER
1070      FSTEP   = 256/(2*NR)
1080      SIZE    = FSTEP*2
1090 '
1100         FOR I = FSTEP TO 256 STEP SIZE
1110            INDEX = INDEX + 1
1120            NDOWN = I - SIZE/2
1130            NUP   = I + SIZE/2
1140            AVE  = (Y(NDOWN)+Y(NUP))/2
1150            Y(I) = AVE + SIZE*(RND(1)-.5)*VR*4/320  'scaling arbitrarily
1160                                                    'based on screen width
1170            SUM   = SUM + Y(I)
```

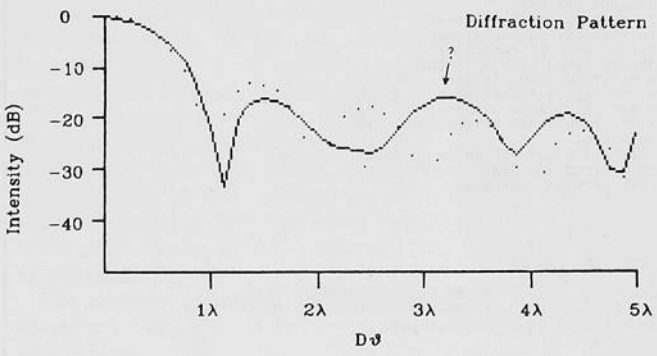

"PERFECT"
Diffraction Pattern
Intensity (dB)
0
-10
-20
-30
-40
Dϑ
1λ
2λ
3λ
4λ
5λ

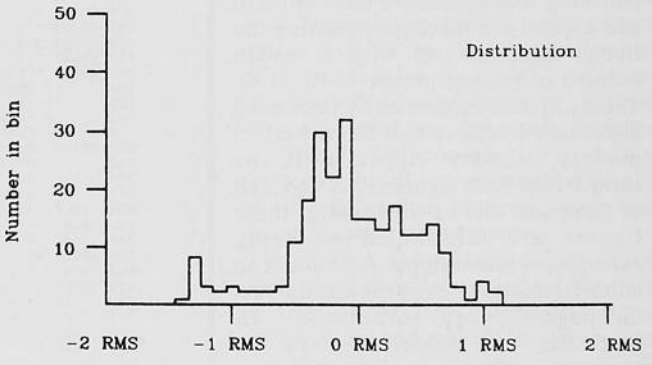

SEED: 1435 Multiplier: 1.03 RMS: .16

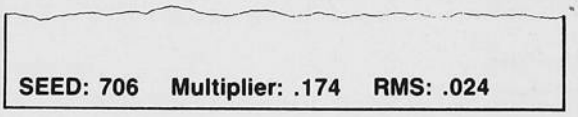

Diffraction Pattern
Intensity (dB)
0
-10
-20
-30
-40
1λ
2λ
3λ
4λ
5λ
Dϑ

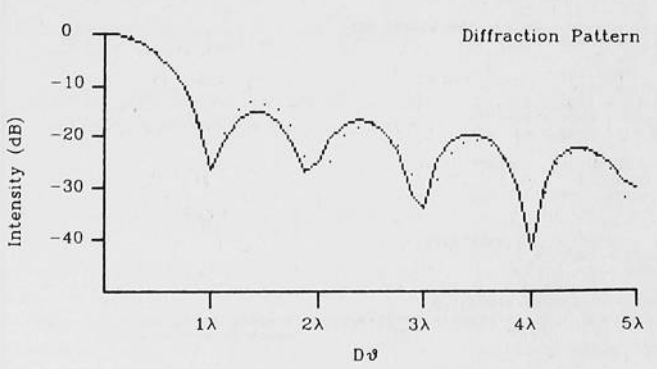
Distribution
Number in bin
50
40
30
20
10
-2 RMS
-1 RMS
0 RMS
1 RMS
2 RMS

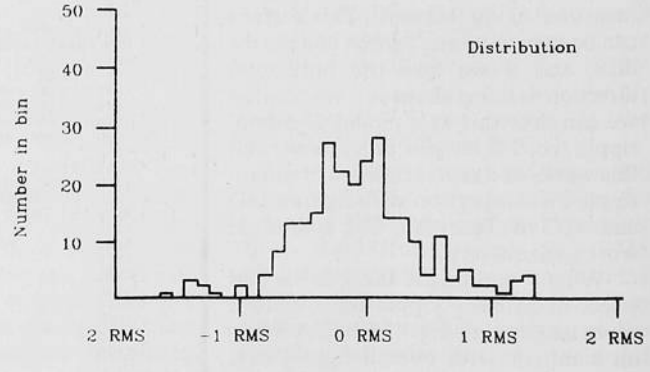
SEED: 1234 Multiplier: .35 RMS: .049

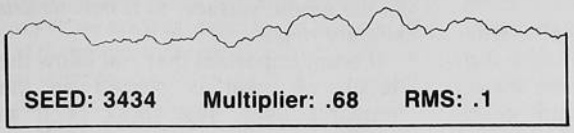

Diffraction Pattern
Intensity (dB)
0
-10
-20
-30
-40
1λ
2λ
3λ
4λ
5λ
Dϑ


Distribution
Number in bin
50
40
30
20
10
-2 RMS
-1 RMS
0 RMS
1 RMS
2 RMS

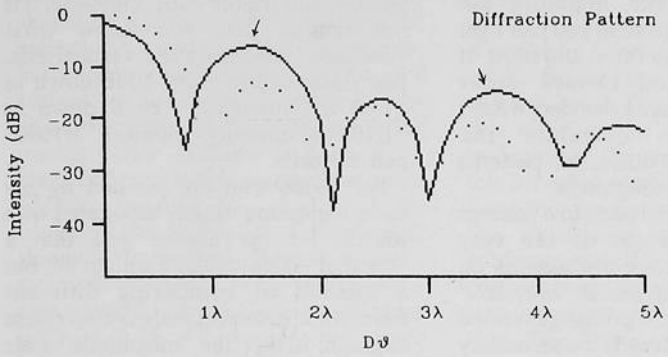

SEED: 706 Multiplier: .174 RMS: .024

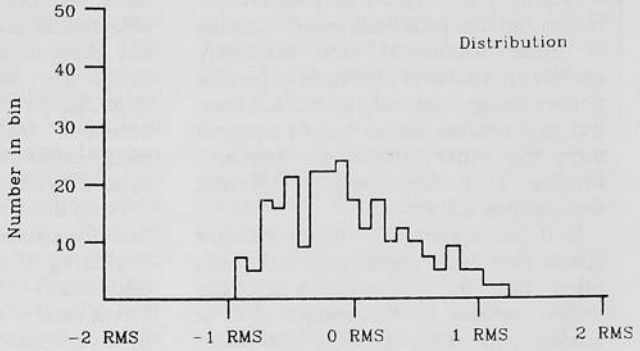

Diffraction Pattern
Intensity (dB)
0
-10
-20
-30
-40
1λ
2λ
3λ
4λ
5λ
Dϑ

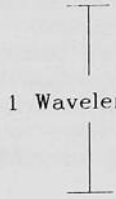

Distribution
Number in bin
50
40
30
20
10
2 RMS
-1 RMS
0 RMS
1 RMS
2 RMS



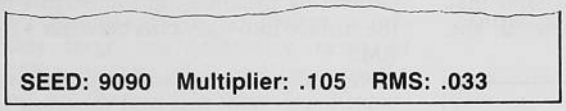
SEED: 3434 Multiplier: .68 RMS: .1



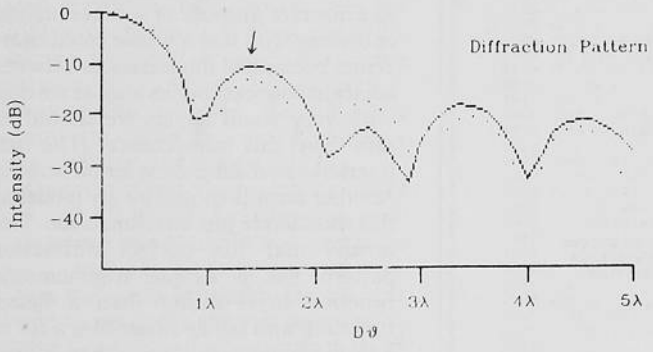


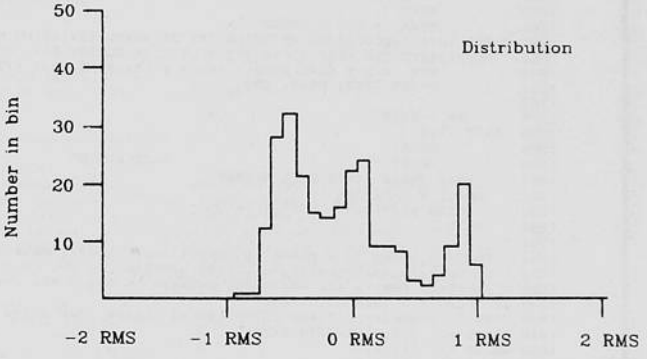


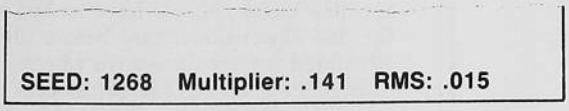
This scale applies to all of the surface profiles.



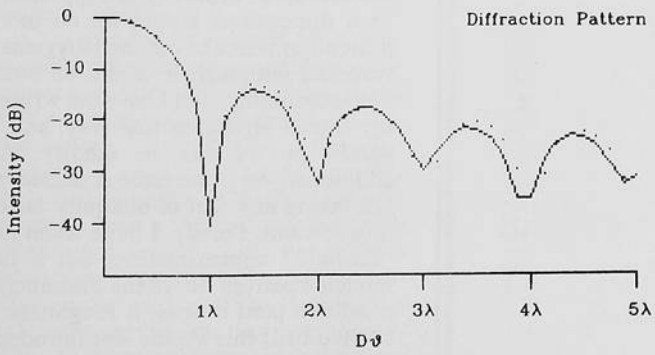
SEED: 9090 Multiplier: .105 RMS: .033

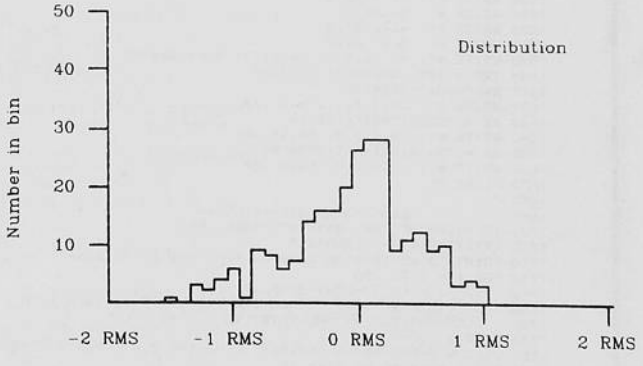






SEED: 1268 Multiplier: .141 RMS: .015





accurate only to ⅛ wavelength on the wavefront?" To understand this we must first define what is meant by "coherence."

Each tiny portion of the mirror that can be viewed as reasonably "straight" in the accompanying figures we'll call a subfacet. A mirror's surface can be broken up into hundreds and thousands of these subfacets, each relatively perfect. A subfacet attempts to form a perfect image from only its surface area, but that perfect image has to contend with the other subfacets' "perfect" images, each describing a different converging wavefront.

If those converging wavefronts are reasonably well correlated with each other, then the image forms from the entire surface of the mirror. But if surface roughness is bad, a significant fraction of the subfacets act independently, interfering with one another to form the blobs and streaks characteristic of inferior mirrors.

Remember that a subfacet's "perfect" Airy disk is a great deal *larger* than the Airy disk formed by the entire surface of the mirror. The ⅛-wave total wavefront is converging smoothly, although imperfectly, from most of the entire mirror surface.

What if we want to get harder numbers about roughness, as I did? Rayleigh's smoothness criterion doesn't help; it is meant only as a crude guide. I found that theoretical calculations of these effects in the literature are remarkably impenetrable; you can't get any gut feeling from them and most of them are oriented toward radar applications anyway. I decided what I wanted was to calculate the modifications in the diffraction patterns caused by surface roughness.

To do this I reached back to a concept that is usually taught at the very beginning of textbook discussions on diffraction — the Huygenian "wavelet." I took each of the 256 points generated by my program and made it a secondary source, with a corresponding phase delay caused by the roughness. I then added the wavelets emitted by these sources with yet another phase shift caused by inclination to the angle at which I want to view the diffraction pattern. Plotting the intensities as decibels versus a reduced variable that is related to angle completed the procedure. This views the rough surface as the whole surface, *so it only models primary ripple.*

It is not important that you know the details of what is plotted on the horizontal axis. Just think of it as "angle" or "arcseconds" or whatever you're comfortable with. Likewise, it is not crucial that you know what "decibels" means on the vertical axis. Just think of the point 10dB down as "1/10 the intensity," 20dB down as "1/100 the intensity," 30dB as "1/1000" and so forth.

For those who are puzzled by my using a measure usually associated with sound, let me assure you that a "decibel" is not really a unit at all, but a method of comparing different intensities. A decibel scale is convenient to graph. In fact, the "magnitude" scale in astronomy is very similar to decibels. The human eye, because it sees different intensities as approximately their logarithm, is better described in terms of decibels or magnitudes anyway.

I have also plotted the distribution of the surface causing the diffraction pattern by breaking up the heights of the surface into forty bins between +/-2 RMS.

Naturally some approximations have been made. The first and foremost is caused by sampling. Taking the surface as a discrete number of sources instead of dealing with it as a whole could cause errors because of interferences between adjacent sources. But as long as we deal with very small angles we should be safe from this interference. (The first interference maximum is far off screen.) Another error is caused by my modeling this situation in just one dimension. This means that the perfect diffraction pattern has a simple trigonometric function in it rather than a Bessel function, and hence resembles a slit or a linear radar array more than it does a two-dimensional aperture.

This is not as bad a problem as it appears. Often, people have looked at the one dimensional case before they attempted the circular aperture because most of the qualitative features occur in one dimension and much of the mathematical difficulty is suppressed. Two dimensions would be no more difficult in terms of adding Huygenian wavelets (although it would be more time-consuming), but I have not written my fractal algorithm that way, and it would be difficult to modify. An additional, very fine error is caused by not taking any sort of obliquity factor into account. Finally, I have taken the "far-field" approximation, but if the modeled pattern obeys the Fraunhofer condition (and it does, if roughness is not too bad) this should not introduce serious errors.

```
1180            SUM2 = SUM2 + Y(I)*Y(I)
1190            PSET(I,Y(I))  'THIS IS NOT NECESSARY BUT LETS YOU WATCH
1200          NEXT I
1210          MEAN  = SUM / INDEX
1220 ' RMS IS A CALCULATION OF TWICE THE STANDARD DEVIATION AND
1230 ' REPRESENTS THE PEAK-TO-VALLEY ROOT MEAN SQUARE DEV. OF THE POINTS
1240          RMS  = 2 * SQR((SUM2 - INDEX * (MEAN*MEAN))/ (INDEX - 1))
1250          PRINT ITER; MEAN, RMS
1260 '
1270       NR = NR*2
1280  NEXT ITER
1290          PRINT
1300          PRINT "                          1 WAVELENGTH"
1310     'NEXT THREE LINES FILL BLANKS
1320     FOR I = 0 TO 255
1330       LINE (I,Y(I)) - (I+1,Y(I+1))
1340     NEXT I
1350 '
1360 ' The following is a plotting output that feeds a metafile in Golden
1370 ' Software's Calcomp-like plotting package. If you do not have this
1380 ' package, remove all statement between here and the next section.
1390 IF IFLAG = 0 THEN GOTO 1690
1400 OPEN "b:fracmir.plt" FOR OUTPUT AS #1 'watch disk drive prefix
1410 WRITE #1, 0,0,5,"A:SET4.SYM"
1420 WRITE #1, 11,11,1
1430 WRITE #1, 01,21,3
1440 WRITE #1, 01,21,2
1450     FOR I=1 TO 256
1460       WRITE #1, I*.02344,2*Y(I),2
1470     NEXT I
1480 WRITE #1, 61,11,2
1490 WRITE #1, 01,11,2
1500 WRITE #1, 01,21,2
1510 WRITE #1, 4.75,31,3
1520 WRITE #1, 5.25,31,2
1530 WRITE #1, 51,31,2
1540 WRITE #1, 51,3.75,2
1550 WRITE #1, 51,4.25,3
1560 WRITE #1, 51,51,2
1570 WRITE #1, 4.75,51,2
1580 WRITE #1, 5.25,51,2
1590 WRITE #1, 4.1,3.9,4,.16,01,"1 Wavelength"
1600 TRU = INT(1000*RMS+.5)/1000                'round off RMS
1610 X$="RMS:"+STR$(TRU)
1620 WRITE #1, .5,3.7,4,.16,01,X$
1630 X$ = "SEED:"+STR$(SEED)
1640 WRITE #1, .5,4.5,4,.16,01,X$
1650 X$ = "Multiplier:"+STR$(VR)
1660 WRITE #1, .5,4.1,4,.16,01,X$
1670 CLOSE #1
1680 '
1690 '          Plot rough distribution
1700 IF (QD$="n") OR (QD$="N") THEN 1910
1710 INPUT "Hit <-'",DUM:CLS
1720 PRINT "Distribution between +/-2 rms in 40 bins"
1730 FOR I = 1 TO 256
1740   YD(I) = (Y(I)-MEAN+2*RMS)*10/RMS
1750   IF (INT(YD(I)) > 40) OR (INT(YD(I)) < 1) THEN 1770
1760   PLOT(INT(YD(I)))=PLOT(INT(YD(I)))+1
1770 NEXT I
1780 WINDOW (-10,-10) - (50,80): LINE (40.5,0)-(0,0): LINE -(0,50)
1790 FOR I = 10 TO 40 STEP 10
```

This model is best when the roughness is small, but this is precisely what we are interested in. In view of all of these approximations, we should look at what the patterns do, not how many decibels we read off the graph.

What do we get? First, by setting the randomness multiplier to zero, we should be able to recover the diffraction pattern of a perfect surface. This is done in the figure marked "perfectly smooth surface" and shows in the other figures as a dotted line. Compare this with the unobstructed diffraction pattern in Steve Edberg's article on apodization in TM#24, keeping in mind that he truncated the description at the second side-lobe. In the other figures we see a steady deterioration of the image as we pass upward from an RMS of .016 to an RMS of 0.16. Of course, the exact pattern you get depends on what seed and roughness you specify. Let's see what kind of behavior we can find.

First, we see that at the "transitional" roughness the image is terrible. A star would look fuzzy. At a peak-to-valley RMS error of 1/10 wavelength the image is still bad — the effects of roughness are unmistakeable. Of course, errors this large are relatively rare. At 1/20-wave, the effects are more subtle, but still the mirror suffers. At 1/30-wave we see, with this particular random seed, a pattern that is worse than the 1/20-wave pattern. I have put little arrows pointing at portions of the pattern that might be annoying. Suppose that we take the following empirical effects as signifying unacceptable performance:

1) an increase in the first two rings of 3 dB (twice the intensity), and;
2) an increase of any of the other rings to 3 dB above the second ring.

Then the point at which the mirrors begin to get really smooth seems to be about 1/40 wave (and please note that I'm basing this impression from many more diffraction patterns than appear here). Thus, it seems that my arbitrary setting of the smoothness limit at 1/60 wave was a bit conservative. Still, I found that some 1/60 wave patterns come perilously close to failing the above conditions, so the "1/40 wave" number should not be taken too seriously.

I have found this cutoff for a one-dimensional example assuming that we would find noticeable doublings of the first or second ring intensities. In two dimensions it could be somewhat different. If anything, it would probably be a little smaller. A perfect circular aperture has a first diffraction ring intensity of about – 17 dB, not – 13 dB as we have been calculating for our one-dimensional example. The fact that we can easily see the first ring even though it is – 17 dB probably means that we are sensitive to scattered light of low intensity. I'd bet my choice of 1/40 wave is not far off, though.

I saw some other peculiar effects. Sometimes the roughness actually seemed to improve the diffraction patterns (look at the intensity of the first ring in the 1/40- and 1/20-wave diffraction pattern graphs and compare it with the perfect-pattern dots.) This effect might be called "roughness apodization." These patterns achieve this effect at the expense of a slight widening of the central peak. I expect this behavior would be modified if I had done this for a circular aperture. Both the statistically higher number of subfacets and different random surface patterns probably conspire to soften the ring structure and "mottle" the first ring. The first ring is probably more prominent at some angles and less prominent at others. The net effect on a stellar image is to put "streaks" through it and "blobs" around it. I wouldn't rely on roughness to apodize my image, nor use apodization as a lame excuse for roughness in my mirror!

I also noticed an effect very similar to central obstruction. The 1/10- wave pattern demonstrates this effect very well. The first minimum is at a much smaller angle than the perfect pattern, but the first ring has expanded to an unacceptable level. I have heard this behavior called "the snake balloon theory of diffraction" — if you step on its head, its tail swells up! People interested in apodization would do well to remember the snake balloon — it puts an ultimate limit to what they can do.

The most common fault of modern machine-polished mirrors is marginal roughness. They are generally made with a serviceable figure within the more familiar 1/4-wave on-the-wavefront (1/8-wave on-the-mirror) Rayleigh limit, but have a mottled primary ripple considerably worse than a 1/60 wave (or 1/40 wave) "second" limit. Their appearance under the Foucault test resembles figure 41A in Texereau, although this is difficult to see in steeply figured mirrors except at the transition from dark to light and at the center of curvature of the central zone.

The appearance in the star-test is more subtle. Little information, as far

```
1800    LINE (I,-3) - (I, 0)
1810 NEXT I
1820 FOR I = 10 TO 50 STEP 10
1830    LINE (-1.5,I) - (0, I)
1840 NEXT I
1850 PSET (0,0)
1860 FOR I = 1 TO 40
1870 IF PLOT(I)>70 THEN PLOT(I)=70
1880   LINE -(I-.5,PLOT(I)): LINE - (I+.5,PLOT(I))
1890 NEXT I
1900 LINE -(40.5,0)
1910 'end of distribution plot section
1920 '
1930 INPUT "Hit <-'",DUM
1940 '  This section does a crude calculation of diffraction effects
1950 '  of this random surface. It does so by adding up wavelets (hoping
1960 '  that 256 is enough) in a simple Huygens description. It has an
1970 '  approximation in that it assumes the angle is very small (it is
1980 '  usually) and that the light is incident at zero degrees. As long
1990 '  as you don't ask this section to calculate too unusual a situation,
2000 '  you should be okay. This section takes a long time to execute.
2010 CLS
2020 WINDOW (-1,-70)-(6,30)
2030 LINE (0,0)-(0,-50):LINE (0,-50)-(5,-50)
2040    FOR I = 0 TO -40 STEP -10
2050            LINE (-.1,I) - (0,I)
2060    NEXT I
2070    FOR I = 1 TO 5
2080            LINE (I,-53) - (I,-50)
2090    NEXT I
2100 DATA .2,.9,2.1,3.9,6.5,10.5,17.1,50,19.3,14.9,13.4,13.5,14.8,17.8,23.7,50
2110 DATA 24.8,20,18.1,17.9,19.0,21.7,27.5,50,28.2,23.2,21.2,20.8,21.8,24.4
2120 DATA 30,50,30.6,25.5,23.4,23,23.9,26.5,32,50
2130 RESTORE 2100:PRINT "Working - please be patient"
2140 LOCATE 2,1: PRINT NSR;SEED;VR;RMS
2150 FOR I = .125 TO 5 STEP .125
2160    READ PERFECT: PERFECT = -PERFECT
2170    PSET (I,PERFECT)
2180 NEXT I
2190 FOR I = 0 TO 5 STEP .125   'units of wavelength
2200    REALEXP = 0: IMAGEXP = 0
2210    FOR J = 1 TO 256
2220            IN = I*(256-J)/256
2230            X = IN - (Y(J)-MEAN)*2
2240            add exp(ikx) together
2250            REALEXP = REALEXP + COS(2*PI*X)
2260            IMAGEXP = IMAGEXP + SIN(2*PI*X)
2270    NEXT J
2280    TOTAL = (1/(256!*256!))*(REALEXP*REALEXP + IMAGEXP*IMAGEXP)
2290    DBTOT = 10 * LOG(TOTAL)/LOG(10)
2300    IF DBTOT < -50 THEN DBTOT = -50
2310    IF I = 0 THEN PSET (0,DBTOT): GOTO 2330
2320    LINE -(I,DBTOT)
2330 NEXT I
2340 BEEP:BEEP:BEEP
2350 LOCATE 1,1: INPUT "                Hit <-'     ",DUM$
2370 END
2380   ' FOLLOWING IS AN "EXAMPLE MOUNTAIN" INITIAL DATASET THAT YOU CAN MOVE
2390   ' IN FRONT OF THE FIRST DATA STATEMENT (USE 8 REGIONS) TO SEE HOW
2400   ' WELL THIS ALGORITHM CONSTRUCTS MOUNTAINS THAT "FEEL" REAL.
2410   ' USE ROUGHNESS PARAMETER OF ABOUT .5 TO .7 ON THE FIRST TRY
2420 DATA 1.0,1.2,1.5,2.0,1.7,1.1,1.0,1.2,1.0
```

as I've seen, has been published dealing with it. I refigured a velvety smooth (very little primary ripple, as determined by Foucault test) but horribly undercorrected Cave 10″ f/6 primary mirror five years ago that was the exception to the rule above.

Before refiguring, the appearance of an out-of-focus star featured rings of surprising contrast and sharpness. Of course, the star-test also revealed the equally surprising undercorrection. I figured the mirror using a fast cerium oxide-base polishing agent, so it probably suffered to some extent from both primary and micro-ripple. Although the mirror was drastically improved by my correction to the figure, the out-of-focus rings had been reduced to a fraction of their former contrast. (I have since taken to finishing my mirrors with rouge, leaving the work of polishing and early figuring to the harsher materials.)

In my article on the star-test (ASTRONOMY, April 1983) I pointed out that high contrast in the out-of-focus rings is evidence of smoothness. Another feature of the out-of-focus rings to look for while searching for roughness is a localized spiky tendency As you consider variation in angle, one of the rings spikes inward or outward and then appears normal at a slightly different angle.

The in-focus rough mirror image has an unusual number of streaks and a defocused halo associated with it. Don't blame time-variations in the appearance on mirror roughness; they are caused by a wavefront "pre-roughed" due to atmospheric turbulence. I'd like to emphasize that this comes from personal observation — these effects may be caused by something I haven't considered.

I have much less experience detecting micro-ripple than I have finding mirrors troubled by primary ripple. Finding micro-ripple requires that you have equipment to perform the Lyot test. I think a manufacturer of telescope making goods would be doing a real service to the TM community by evaporating on a single microscope slide a series of slit-shaped (about ⅓ to ½ millimeter wide and a centimeter long) phase-plate regions with correspondingly higher densities. This plate would replace the knife-edge in a conventional Foucault test (only with a wide slit), and would make the sophisticated Lyot test for micro-ripple available to amateur telescope makers.

In the star test, micro-ripple would be visible in the in-focus stellar image by having a much larger halo. Indeed, the effect of micro-ripple is probably very similar to having dirty optics and contributes to the degradation of bright images. I would say that if you have clean optics and a crystal clear night (be sure to check your eyepiece for cleanliness, too) but still see a significant halo around bright stars, you have a problem with micro-ripple.

I have witnessed another effect on a few machine-polished mirrors that I have never seen on hand-polished mirrors: six beautiful spectra spread outside the image circle as I defocused the image. It wasn't related to the spider; I saw it with four-vaned spiders. Based on the amount of dispersion, I provisionally assigned this effect to an unfortunate regularly-spaced machine-produced periodicity at the micro-ripple level, causing the mirror to act like a diffraction grating. I don't know why this effect doesn't appear while in focus.

What do you do if you suspect that a mirror has a problem with surface roughness? First, determine whether or not the mirror needs surface smoothness. If you've got a super-fast deep-sky reflector, surface smoothness isn't critical. You should only use such instruments at lower magnifications and you seldom use it on bright objects anyway. Smoothness just isn't a low power/low brightness problem.

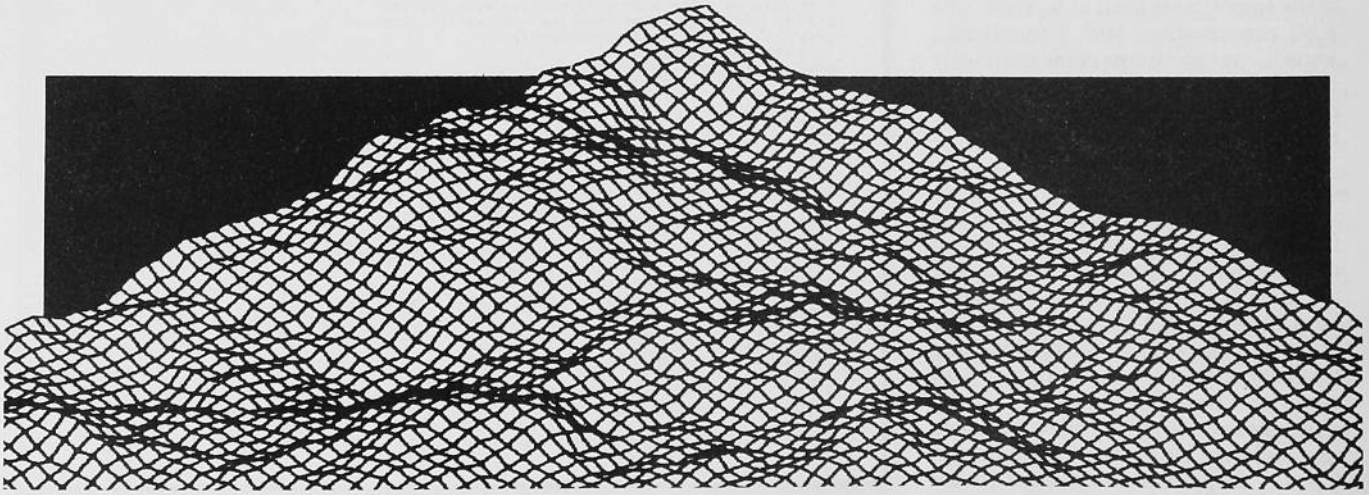
If you call up a well-known California manufacturer of f/4.5 Dobsonians to complain about surface smoothness, he will laugh in your face — and rightly so. He has made certain trade-offs between instrument quality and production time with a view toward maximizing the performance of the instrument at a price the customer is willing to pay. This isn't dishonest unless he advertises the mirrors as being of highest quality, which he does not.

On the other hand, if you are buying a parabola of f/9 or f/10, and paying a high price for this obviously lunar-planetary mirror, you have the right to demand and receive high quality. In dealing with manufacturers, my advice is to be gentle.

People who use refractors might wonder how all of these mirror calculations might be modified to allow them to make statements that concern them. A mirror's "index of refraction," the number that you formally insert into ray-tracing calculations, is −1.00, differing by 2 from the index of refraction of air. The index of refraction of glass is approximately 1.5, differing by 0.5 from that of air. Thus, a mirror is *four* times as effective as a deflector of light than glass is. From this argument we might anticipate that RMS error on a refractor surface can be four times as big as error on a mirror to yield the same diffraction image distortion.

But in doing this we have neglected two important factors. Doublet refractors have four optical surfaces. Furthermore, some of the errors cancel errors made on other surfaces. Instead of boring you with the details, let me give you the result: Refractors with twice the surface RMS error of mirrors perform comparably, or refractors with the same RMS error perform better than the mirror. But note that this does not include 3- and 4-element refractors, nor folded refractors.

This tends to favor the refractor over the mirror telescope, but it is by no means a killer blow. There is no reason



that a person who is *aware* of the problem can't make a mirror that performs with the same smoothness of wavefront as the refractor. The real problem is in NOT knowing, and accepting the first thing to come off the lap.

Mirror-makers may want to know how to recognize roughness and deal with it in fabricating a mirror. The best advice I can offer is to follow the instructions in Texereau. The choice of materials, choice of stroking technique, and degree of contact that you achieve affects the amount of roughness you generate.

Look for primary ripple by using the Foucault test with a narrow slit. Check to see if you are having trouble when the mirror is very near a sphere, where the Foucault test is most sensitive. Then check it again when you are nearly figured by looking at the center of curvature of the central zone. If the brightness of the nearby steep curves bothers you, block them off with a card. If you can see any streaks or a dog-biscuit problem, you have too much roughness.

A test for microripple will have to wait for an enlightened manufacturer to step forward with a phase-plate. Until then, you'll just have to hope that gentle technique and proper choice of materials will automatically eliminate this error. Your suspicions can be aroused by the appearance of strong halos around bright objects even with clean optics and clean air.

There is another form of roughness that we haven't considered here — zones, that is, roughness that is a figure of revolution. This is no more acceptable than random roughness. Since people are more aware of zones than random roughness, and zonal errors are more of a problem with the overall figure, we'll let the matter drop.

I once made a simple calculation of the relative severity of various diffraction errors from otherwise properly figured mirrors, keeping in mind where the scattered light was and how densely it appeared, and making some educated guesses. The two greatest errors were caused by spider vanes that are too wide and primary ripple. I believe that as the quest for aperture cools down and TMs turn their thinking to obtaining higher quality, they will begin to pay more attention to roughness in their mirrors. Surface smoothness is crucial to obtaining the excellent performance that so many observers find important.

Dick Suiter
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Notes on Computing the Apodized Image

Stephen Edberg's article about apodization in TM#24 will do much to clear the air. In recent years, apodizing has spawned a lot of mythology among amateurs; I think Edberg's article will at least cause people to think about apodization.

I have a few small complaints, however. The first is related to the geometry with which these calculations were done. I believe that Edberg should have mentioned that he made these calculations in *one dimension*, for a slit-type aperture. Although such work can be qualitatively transferred to the circular aperture (I've done it myself), I think the reader deserved a warning of this situation.

My second gripe deals with one of his results. I have repeated Edberg's calculations, and in general I got the same results as he did. The Gaussian pupil function severely reduced the rings at the expense of overall resolution. The annulus resulted in a narrower main lobe but stronger rings. I reproduced nearly everything he mentions in the article except the pattern of the flat profile turning into a Gaussian at 0.8 of the radius. He indicated that this resulted in nearly complete apodization just as the conventional Gaussian did, but without such a serious loss of resolution. The diffraction diagram he shows displayed no side lobes down to −40 dB intensity.

My calculation, on the other hand, shows no significant improvement over an aperture of about 0.9 times the diameter. I repeated this calculation for a number of situations and functional forms, both in one and two dimensions, and I found no way of improving the resulting image until I softened the function sufficiently that it began to resemble the overall Gaussian again. I conclude that Mr. Edberg is in error on this one. This would not have made much difference, except that many of his real screens seemed to follow this unfortunate form.

About the figure: Apodization of a circular aperture's diffraction pattern is calculated for a pupil function that has a Gaussian taper outside 0.6 of the radius. Dots denote unapodized pattern. Although this is a milder drop-off than Edberg used, in this situation, where we would expect even better reults, apodization of the first ring is minimal (about 2 dB). A Gaussian taper beginning at 0.8 of the radius looked even worse.

I'd also like to take issue with a few points in his letter in TM#26. While it is true that *individual apertures* would have this "uncertainty" trouble, his analysis does not apply to diffraction gratings (or screens). With diffraction gratings, distant apertures are still well correlated with each other, so their resolution is indicative of the *whole aperture* rather than the individual openings. As long as you are considering the zeroth order image, well-separated from higher order diffraction maxima, I see no reason why you cannot model a screen by using its effective transmission.

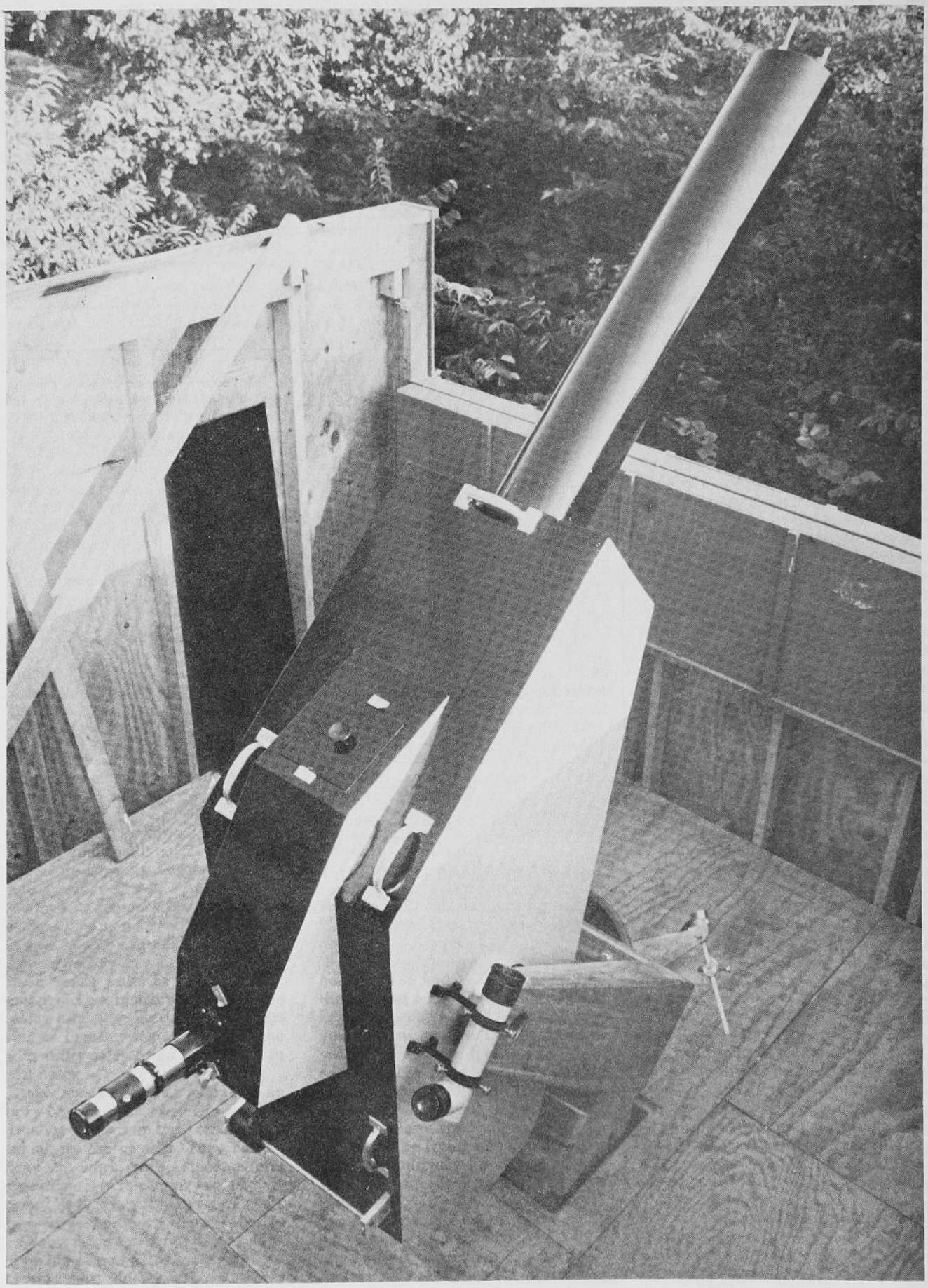
Still, I agree with his overall conclusion that, if apodization works at all, there may be something happening that is more complicated than instrumental optics. I've noticed similar effects myself. For example, it is much easier to see the disk of a Galilean moon if it is very near the dazzling image of Jupiter. This effect could be caused by irradiation of the retina inducing localized temporary loss of night vision, thus making it much less sensitive to external "trash" around the image spot. In effect, a kind of apodization occurs. As the moon moves away from Jupiter, this image "trash," comprised of abberations as well as diffraction rings, reappears. A lot of what I've heard about using screens for apodization seems to involve putting stray background light in or near the image and can perhaps be explained similarly.

Maybe we don't need to block the aperture or do all of these horrifying calculations. Perhaps all that's needed is a low-intensity lamp across the tube from the eyepiece! It seems odd that lowering the contrast should be a way of improving definition, but it's certainly possible. The capabililties of the human eye have surprised people before. More work has to be done to discover just what effect improves the image.

— Dick Suiter

P.S. In another letter (TM #26), Art Leonard implied that apodization is hopeless or impossible for a telescope with a central obstruction. As long as the obstruction is kept below 20% of the diameter, my calculations indicate that usable filters can be made. They result in less spectacular apodizations, that is, they do not suppress the diffraction rings as far, but they are certainly better than the original obstructed aperture.

P.P.S. I am absolutely amazed that people haven't mentioned the massive review article on apodization by Pierre Jacquinot and B. Roizen-Dossier in Volume III (1964) of *Progress in Optics*, ed. by E. Wolf. This article is 155 pages long and what it doesn't say about apodization isn't worth saying.



Building a 12.5″ Buchroeder

TRI-SCHIEFSPIEGLER

For years I have sought the "ideal" telescope, because my principal work is lunar and planetary observations for the A.L.P.O. Although I have been building and using 12.5″ Newtonians and Cassegrainians for years, the inconveniences associated with both types of instruments eventually began to loom large. With the Newtonian it is the ladder and the awkward observing positions. With the Cassegrainian it is sky flooding and a large secondary obstruction. It seemed that everywhere I turned compromises had to be made. How could I get around these and still have the best optical results?

I decided to make up a list of requirements for my next permanently-mounted instrument. I had begun the list years earlier but, by the time I was ready to build this telescope, the list had grown quite long. Size was not important to me, since the instrument would be mounted in my observatory and could be quite large. I had conceded to a focal ratio of f/20 or so, if necessary, since long focal length eyepieces that yield fairly low magnifications are available today. The list went something like this:

1. No optical or mechanical obstruction in the optical path.
2. No ladder needed to look into the eyepiece.
3. No color, however small, in the image.
4. A Newtonian image orientation.
5. Fork mounting for photography at the zenith.
6. No star diagonal needed.
7. No Barlow lens needed.
8. No extra weights needed in mounting a camera.

The Buchroeder Schiefspiegler is painted bright yellow and black. Note the folding south wall to enable seeing low southern objects.

Building a telescope like this seemed an impossible task, but I'm in this hobby for life, so why not give it a shot? I thought. Besides, I said to myself, if I'm successful, others may benefit.

Bob Cox has been writing articles on the Schiefspiegler for years and he inspired me to investigate this design. His articles go back to the 1950s, but I have read them all. The biggest advantage of the design is that it has no central obstruction, which is one of my requirements. But wait, there are problems. With a two-mirror system a person could end up in the hospital with a twisted neck after ten minutes of observing. As with a refractor, the eyepiece position moves all over the interior of the observatory when the instrument is pointed at various objects. With three-mirror systems, the image orientation is wrong. I studied the Kutter Tri-Schiefspiegler, but a 12.5″ didn't work because scaling a design from one with an aperture of 4.25″ caused aberrations to exceed tolerances. Anyway, it seemed difficult to use with the eyepiece in the midde of the tube.

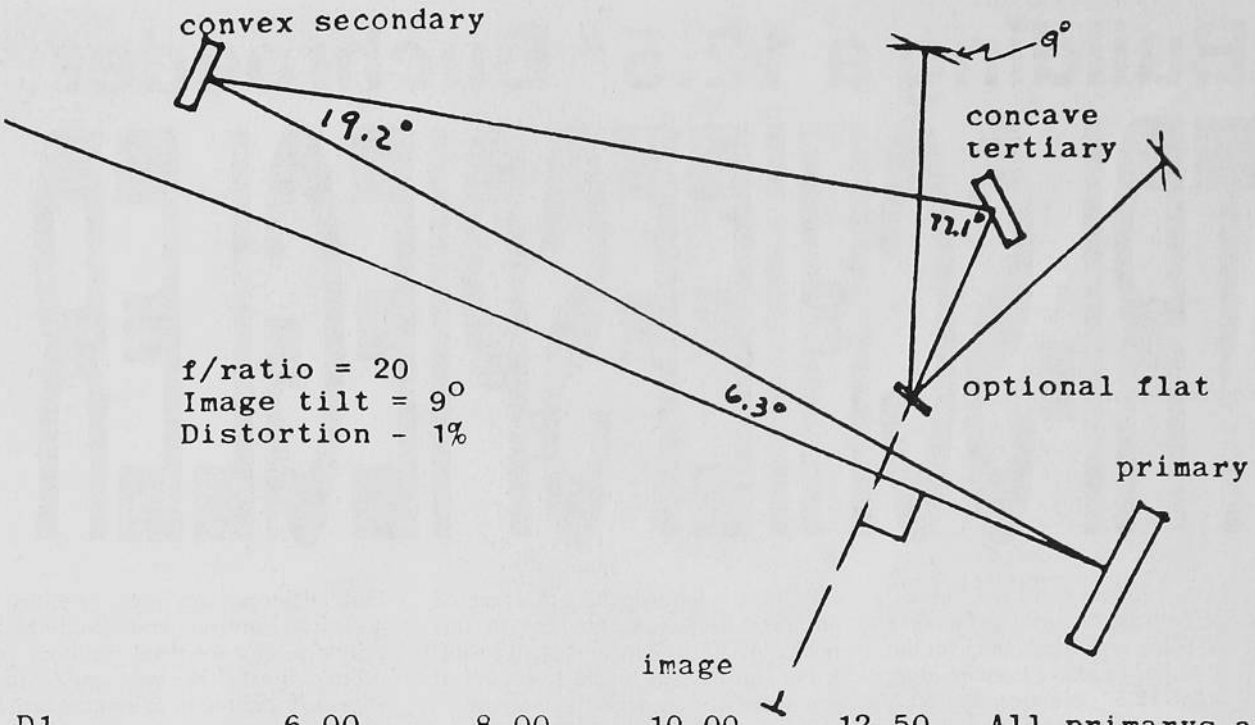
Somebody had to put this design together so a human being could use it.

The Kutter Catadioptric Schiefspiegler built by Robert Schmidt and presented in *Telescope Making #4* intrigued me to the point of trying to make it work. I was able to insert an optical flat behind the correcting lens which made three reflections. This brought the focus up past the primary and made the instrument more compact, but it gave the wrong image orientation. Adding a star diagonal corrected the orientation for A.L.P.O. work. Most everything on my list was in this telescope except for the star diagonal. And there was the question of color. Nobody knew much about color in a 12.5″ since only Kutter and several European amateurs had built telescopes this large. I decided to go ahead anyway and build an 8″ prototype and see what resulted.

Building the 8″ was easier than expected, thanks to Schmidt's article, and the result was a big success. I thought I saw some color on Jupiter's limb sometimes, although it may have been caused by the atmosphere. But I despised the star diagonal. That had to go in the "big" one! I asked Bob Cox about the color problems in a 12.5″ and he wrote to Dick Buchroeder about them. The consensus was that it would be better to build a Tri-Schiefspiegler than a catadioptric. But I didn't like the eyepiece position in that design. Now what?

In 1972 I had written to Dick Buchroeder about the three-mirror equal radii Schiefspiegler design he published in *S&T*, December 1969. There were some problems with it, at least for my type of observing, so he sent me an improved design. The price for the improvement was making a concave tertiary mirror — with a radius of 2096″. The eyepiece position came out similar to Kutter's Tri-Schiefspiegler and it also had three reflections, so I stored it away in my files. Besides, the tertiary mirror fabrication scared me!

When Bob wrote about Dick's reply on color he included a booklet Dick had written on tilted component telescopes, which included spot diagrams for a variety of designs, among them Art Leonard's Yolo designs. I considered Leonard's 3-D design, even made a model of it and, although optically excellent, it was just too bulky in a large size. I also saw the analysis of Buchroeder's design, the same one he had sent me eleven years earlier. I compared the spot diagrams of the Kutter Catadioptric to Buchroeder's three-mirror design, and Buchroeder's



D1	6.00	8.00	10.00	12.50	All primarys are
R1	-144.00	-192.00	-240.00	-300.00	55% corrected
D2	2.88	3.84	4.80	6.00	spherical
R2	144.00	192.00	240.00	300.00	
D3	2.88	3.84	4.80	6.00	spherical
R3	1006.00	1341.00	1677.00	2096.00	
Distance1	41.04	54.72	68.40	85.50	
Distance2	32.11	42.82	53.50	66.90	
Distance3	21.31	28.42	35.50	44.40	

Distance 1= primary to secondary
Distance 2= secondary to tertiary
Distance 3= tertairy to focus (insert optional flat in here)

was far superior. The Kutter design appeared to suffer from considerable color problems, at least on paper. Although the eye might not see them, the decision was simple for me: an all-reflecting system for the big one!

However, one large problem still remained: I had to arrange the optics to work and meet requirements 2, 4, and 6 — no ladder, Newtonian image orientation, and NO star diagonal. I did a ⅛-scale drawing of the optical layout and began to study it. I realized that I needed another reflection from an optical flat for image orientation, so I placed one past the tertiary. It reflects the light path back on itself, to one side or the other of the tertiary. The light now exited from the side of the tube opposite its location in the original design.

Then I turned my drawing over and studied it. The fourth mirror did a remarkable thing; everything fell into place! The Newtonian orientation was there, no star diagonal was needed, the bulk of the telescope was out of the observer's way so it would be convenient to observe at the zenith or horizon without a ladder, and there was absolutely no color. I couldn't believe that I had succeeded in meeting all my requirements in one telescope. It was also easy to fork mount. The mass of the telescope was out of the observer's way, and the eyepiece was close enough to the balance point that no extra weights were needed when a camera was added for eyepiece projection photography.

I was now very enthusiastic about the whole project. Since I had already built the observatory, I built a model of the telescope to see if it would fit. It did, though it would be tight in some places. I decided to go ahead with the project in September 1983.

A 12.5" Buchroeder Schiefspiegler is a complicated instrument. Building one requires considerable planning to anticipate and solve all the subtle problems that will occur during construction. It's necessary to work out every detail, at least in your head if not on paper, or the the whole project could come to a screeching halt or require major redesigning if you forget something important. The time to get the design right is early on, before you do any construction. Plan all the things you want and design out all the problems before you begin construction. I did this with a scale drawing before I began the optics. In spite of my care, I ended up making a tube modification late in the assembly.

Making the Optics

Since the primary and secondary in this design have the same radii, they would be worked together, and I really didn't anticipate problems with them. I decided to work the tertiary mirror first as it presented the greatest problem. I had never made optics with so long a radius. If I overcame this challenge, the rest would be easy.

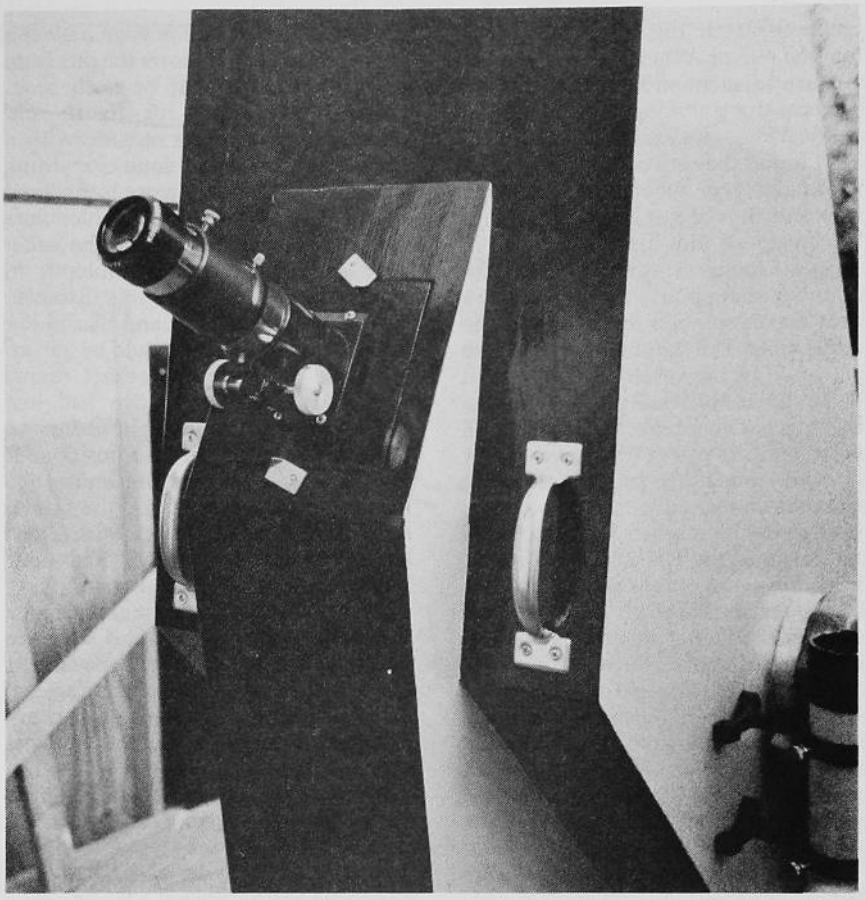
I had to find a nearly flat area long enough to accommodate the test path for the tertiary. The 175 feet required for testing meant it had to be done outdoors. I placed the mirror stand at one end of the yard, propping up some spruce tree branches to get a clear light path, and stuck a screwdriver in the ground to indicate my radius goal. I used an electronic spherometer borrowed from work during grinding, and it helped me get close to radius the first try. The spherometer made checking the sagitta — only 0.002" — easy during grinding.

The first step was to clean up the blank and tool completely with #80 grit, while keeping them as flat as possible. When the spherometer showed the depth to be correct I placed a straightedge on the concave — hardly any light could be seen under it! Without a straightedge it was impossible to see the curve on the mirror suface.

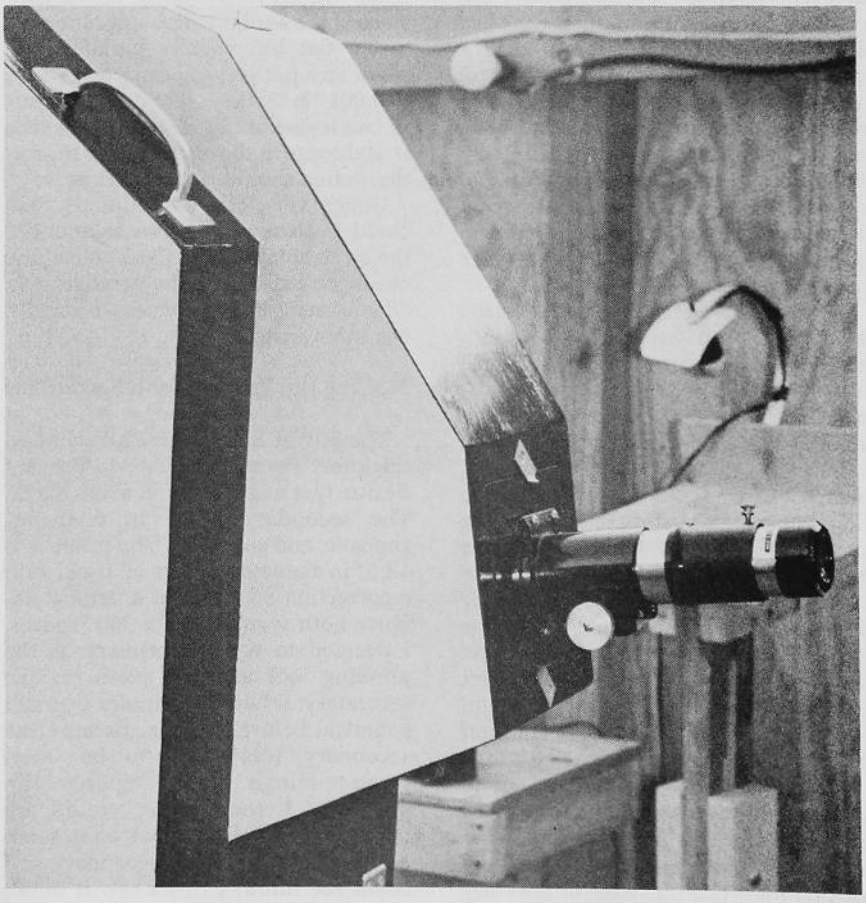
Taking the mirror up to 1 micron grit went very fast. Making a lap on another blank, since I knew that I would have to regrind the mirror with fine abrasives to adjust the radius, I put a flash polish on the mirror surface. A flashlight reflection test outside revealed the radius was 10 feet short! Even with expensive and fancy tools you don't get a radius this long on the first try. It was an important lesson in dealing with so long and sensitive a surface.

Even though the radius was 10 feet off, the spherometer had done its job and had gotten me close enough so I could reach the final radius control by regrinding and flash polishing it. With the mirror on the bottom, I ground it with 3 micron grit for a minute or so, then finished on 1 micron abrasive. After two or three repeats I had the radius where it should be.

For quick testing of the radius and figure I used the test suggested by Bob Schmidt in *TM#4*. I tried this method using a very powerful flashlight. Hold the flashlight and use a white cardboard



The eyepiece holder in the upper position which is usually used for objects overhead or to the northern part of the sky.



The eyepiece holder mounted in the lower position which is usually used for Lunar and planetary observing. Note the drawing stand, with light, in the background.

screen to catch the image returning from the mirror. When the card and the bulb are adjacent and the image of the light is as sharp as possible, then the two are located at the radius of curvature. I first found the reflection by eye, then placed the card where my head had been and moved back and forth until the image of the flashlight was in sharpest focus. I then marked the ground at that point. From there to the screwdriver stuck in the ground is the radius error. The flashlight method is so fast you'll be impressed. The powerful flashlight is necessary because the mirror is not very reflective with a flash polish on it. If you're off to one side or the other, remember the radius is an arc centered on the mirror.

When the radius was correct, I found the image of the flashlight was rather fuzzy, indicating a nonspherical surface. To find the surface error, I used a simple two-mask system. I covered the central 3" inches of the mirror and found the sharpest image formed by the outer zones. The second mask blocked the center 3" inches, and I found the location of its sharpest image. By adjusting the stroke I brought both these zones into coincidence, making the mirror spherical.

It is probably better to regrind with 3 micron or even 1 micron grit to correct this type of error, especially since the error probably occurred during the last adjusting step when you didn't completely smooth the mirror surface.

Once the image was at the correct radius position, and sharp by the above test, I continued to a full polish, flipping the mirror and tool positions to control radius and make minor radius adjustments. Long radii move rapidly in polishing, so frequent checks were needed.

To check for a complete polish I used a professional method. Although examining the surface reflection of a nearby bright bulb isn't a perfect test, most mirrors will have a satisfactory surface using this method. But if you really want to be sure no pits remain, use a lens to focus an image of the filament of a very bright bulb on the surface of the glass. View the surface with a low power magnifier. When the surface is clean and free of any oil or dust, then you will be unable to see the image of the filament. As long as you can see the image, the surface isn't polished out. The small final pits stand out if you have a dark background behind the glass.

The most recent and best test is to place the mirror on a light box and place a ruler under it. Using a 10x loupe (magnifier), examine the surface, looking for pits at the edge of the ruler shadow — the transition edge between dark and light. This allows the pits from an incomplete polish to be easily seen.

The final testing for figure and smoothness was done outside with a Foucault test. If I had done everything well, I would be very close to finished at this point. I used 11x80 binoculars (one eye), set up right behind the knife-edge and focused on the mirror, to inspect the mirror from this distance. First I found the image and placed the tester so the knife-edge could be moved inside or outside of the exact radius point. After the knife-edge had just begun to to cut into the light beam, the telescope was moved into position. It was now easy to find the knife-edge location for the test. If you use a telescope finder so the image is inverted and reversed, don't let it fool your interpretation. Wind currents were usually not a problem for me, since they were either rushing past and could be averaged out, or were very sporadic. I just waited for moments of good seeing, as you do when observing. When my mirror looked perfectly smooth my final radius was 6" too long.

It should be evident that making a very long radius sphere can be accomplished without fancy equipment. In grinding, use a metal straightedge to check the sagitta against a feeler gauge 0.002" thick. Incidentally, check both sides of the straightedge, since they are rarely flat but usually parallel. The cover on a package of cigarettes is close to 0.001" in thickness, so if you can just fit two layers of this material under the straightedge at the center of the mirror, the radius should be fairly close.

Under very crude conditions, you could work so you just see light under the straightedge, then flash polish and check the radius with the flashlight test. Of course if you have access to gauges, use them instead.

Making the Primary and Secondary Mirrors

The mirror blanks were all standard thickness Pyrex, adequate to prevent flexure that might occur in a thin blank. The secondary is 6" in diameter, concave, and spherical. The primary is 12.5" in diameter, and an ellipsoid with a correction 55% that of a paraboloid. Since both would have a 300" radius, I decided to use the primary as the grinding tool and test plate for the secondary, while the primary was still spherical before figuring. Because the secondary was going to be interference-fringe tested against the primary, I realized it would be necessary to polish, or at least semi-polish, the back of the secondary so I could see through it. I knew it didn't have to be optically flat, but it had to be flat enough so that it would not distort the fringe pattern. To grind it I needed a flat tool. I decided to work the primary, secondary, and back of the secondary through each grit before changing to a finer one; I felt this would minimize the chance of scratching due to contamination.

I began with #80 grit, roughing out the primary first on a full size tool and using the penlight test to test the radius. I tried to hold the radius between 300" and 303". Next I ground the back of the secondary back flat against its tool. The secondary face was ground convex on the primary until it matched the primary, using the pencil test. Once they matched, I found it necessary to regrind the primary on its full size tool to true up the radius. Grinding the secondary had shortened the primary's radius, so I brought it back to 300" again and then reground the secondary on the primary until the two radii matched again. After both mirrors were on radius and spherical, I continued work on the back of the secondary. Straightedge flat is sufficient for testing.

Fine grinding proceeded normally through the grits. I kept a close watch on the radii and made sure they stayed equal. Remember that the back of the secondary can have pits and does not need to be fully polished out, just polished enough to easily see the fringes.

The primary should be polished before the secondary since this concave surface will be used as the test plate for the secondary. To make things easier, I polished the back of the secondary first, using the nearly flat lap I had used for the tertiary. I polished the secondary back with that lap and then stripped it to use as the polisher for the secondary, since I wanted the pitch on the secondary pitch lap to be identical to the pitch on the primary lap. Because interference testing does not as readily show the smoothness of the figure as the Foucault test does, I would use the primary's surface to "prove" the quality of both laps. Then, while I was polishing the primary, I would monitor the quality of the polish using the Foucault test. If the primary lap wasn't working right, then neither would the secondary lap. In this manner I would be able to control the quality of the pitch on the secondary lap and would end up with a better surface.

I poured both laps at the same time from the same melt of pitch. As it turned out, I had to remake these laps three times before I had the correct pitch temper and was happy with the results I was getting polishing the primary. This seemingly trivial point is

the single most important factor in getting perfect figures on the mirrors.

I polished the primary in the normal fashion to maintain radius and smoothness of figure. At this stage it is imperative that the figure be the best sphere that you can make. There must not be any zones and you should see a clean, bright diffraction line around the whole edge of the mirror when it is nulled with the tester. Don't allow any air currents in the light path during final testing; these could mask zones or other imperfections.

One of the secrets of the Schiefspiegler and why it works so well is that the primary and tertiary can be tested to better than 1/50-wave using the Foucault test! This is due to the long radii and slight depth of correction.

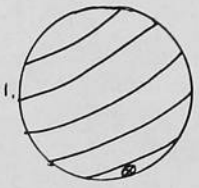
When the primary was fully polished and figured to a perfect sphere, it was time to begin work on the secondary.

I polished the face of the secondary until it had enough shine to obtain a fringe test of its convex surface on the primary's surface. I didn't work too long because I might be working in the wrong direction to obtain a correct figure! Once you know the figure you know which way to work the surface and can keep tight control over it. I worked to produce straight and uniform fringes and to keep their edges as smooth and regular as possible. Kinks or squiggles are not allowed if you want maximum performance from the finished system. A deviation of 1/5 of a fringe is fairly visible, especially if you place a straightedge along the edge of a fringe. Attaining this much deviation indicates a figure of at least 1/10-wave since the distance from the edge of one fringe to the same edge of the next is ½-wave, and you can probably do better.

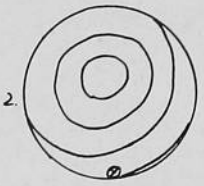
The first test you do will probably show arcs or a bull's-eye pattern instead of straight fringes. This is because the two curves no longer match. Even if the radii were exactly the same when you finished fine grinding, you will have changed its radius in polishing and figuring. Even if the radii had not changed, there would still be a small difference due to the thickness of the layer of abrasive between the two pieces of glass resulting in a convex fit.

You'll get the best fringes if you use a monochromatic light source; the more monochromatic, the higher the fringe contrast. A good source can be made with a mercury bulb covered with a green diffusion screen. I use regular fluorescent bulbs and hold a narrow-band green filter in front of my eye. This isolates the green line of mercury at 5461 Angstroms with a wavelength of 0.0000215". A neon bulb will work, but

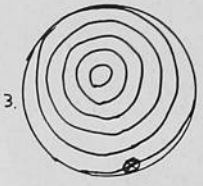
Flash polish. Fringes move away from X. Concave



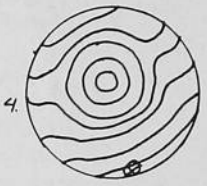
2) Halfway polished out. Arcs have turned into rings of power. More concave as fringes move away from X.



3) Secondary completely polished out, except edge Most concave condition. 5 rings of power. Pattern moves away from pressure point X.

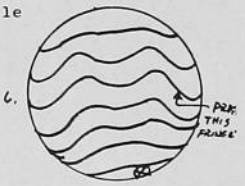


4) Modified lap with mylar star. Edges are becoming steeper and a closer match to the TP. Where fringes are straight they match. The edge is slightly turned up with a very concave center. When pressure is applied at X the central portion moves away from X while the straight section stands still and the very edge moves toward X. Very aspheric surface.

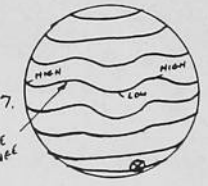


5) Continuing with the mylar star lap. The matching edge is moving more into the central section of the mirror with more polishing. The edge is more turned up with a match inside the edge and still a concave center. When pressing at X the motion noticed is primarily the central section that moves away from X.
In all cases, press hard enough at X so that the thinnest air space is at X. The fringes will grow closer together as you press when this condition exists. The fringes then show the profile of the surface from the pressure side.

6) At this point the mylar star is pressed out and the full lap is used. The very edge is still up along with the rest of the surface except for the very center that is still a little low, and looks like a hole in relation to the rest of the surface. The basic figure is slightly convex with irregularity. The surface is now fully polished.

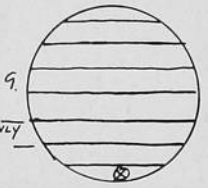


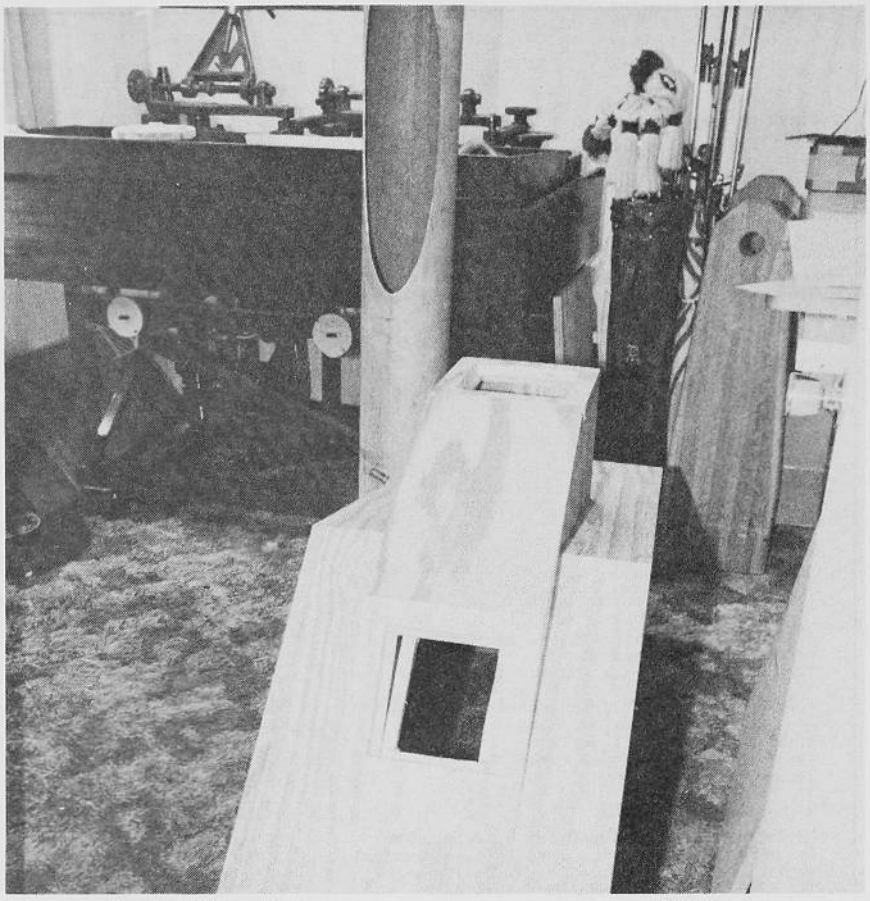
7) Full lap polishing continues. The surface is greatly improved with a high edge, slightly convex inside the edge and a slight hole in the center. Working the edge of the surface over lap with slightly accented pressure will drop the edge, but be cautious. Don't overdo it. The hole will come out with continued polishing as is in process. Continue as before. COLD PRESS OFTEN.



8) Very slight irregularity left.

9) Finished secondary.





The back of the tube assembly during construction. The two eyepiece holder positions are shown. Note the tube for the secondary and the cutout that had to later be enlarged. The fork sits next to my golf clubs, giving perspective to its size. My two-spindle lapping machine is in the background.

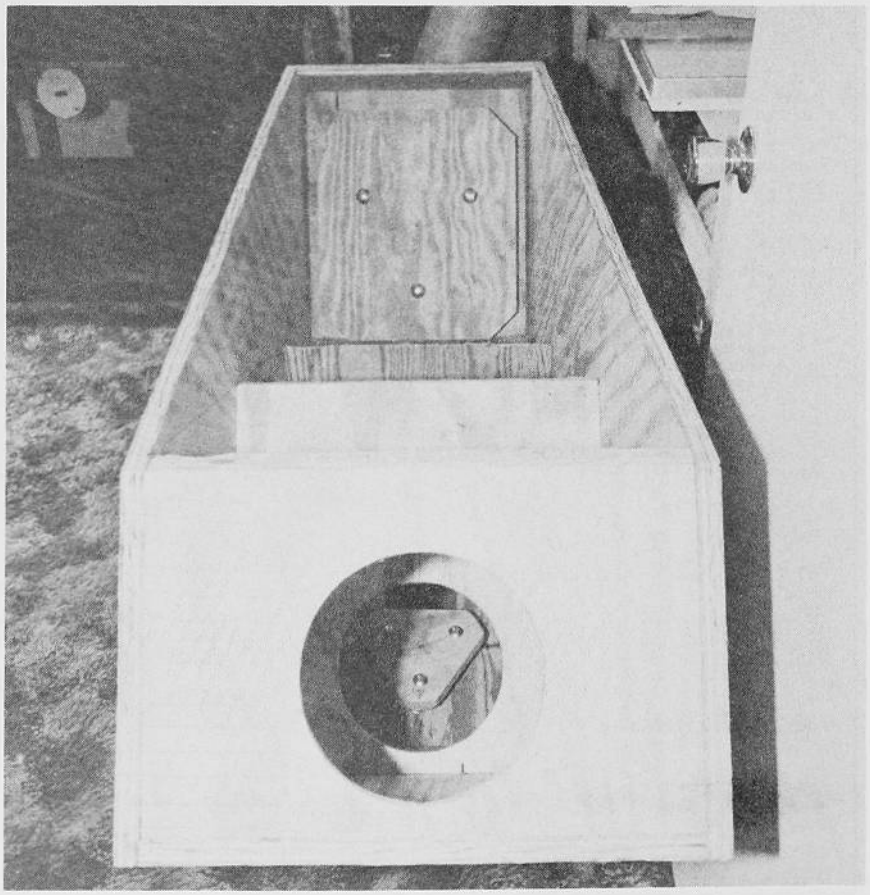
unless a filter is used to isolate one wavelength, you'll see overlapping fringes from different spectral lines in the lamp, and their edge sharpness will be difficult to estimate.

Your goal in conducting the interference test is to bring the surfaces close together and parallel, but not touching. Place three pieces of scotch tape spaced 120° apart around the edges of the secondary, then gently bring them together. When you press lightly with your finger, you compress the tape and thereby introduce a slight wedge in the airspace. You will notice that the fringes and shape then change. This doesn't mean the optics are warping; but rather that you are changing the airspace.

The circles you see in the first test are what we call "rings of power;" their presence shows the radii are different. If the whole pattern moves away from the pressure point, then the two surfaces are concave to each other, meaning, in this case, that the secondary is longer in radius than the primary. If the pattern moves toward the pressure point, then the surfaces are convex to each other and the radius of the secondary is shorter than the radius of the primary. This difference must be corrected before sensitive testing for fringe straightness can be accomplished.

When the radii are exactly the same the fringe pattern will consist of perfectly straight lines. If you press with your finger, more fringes will crowd onto the mirror. Position the fringes so they are 90° to your line of sight, or "horizontal" to the eye. This can be done by applying pressure around the edge of the secondary, or by rotating the mirrors and the fringe pattern between.

To evaluate the surface you'd like four or five fringes to be visible. Evaluating the figure is quite simple. When you view the mirror from the side where pressure causes more fringes, then the surface has the same contour as the edges of the fringes! If a fringe turns up at the edge of the surface being tested, then the surface has an upturned edge. If the fringes bend down in the center, then the center has a depression in it. You must master this interpretation if you hope to figure the



The wooden tube assembly under construction. The primary mirror cell is at the top. Looking through the two round holes, where the secondary tube will mount, is the tertiary mirror mount.

secondary. The accompanying diagrams and explanation show how my secondary appeared upon testing and how the surface changed during polishing and what was done to finally achieve the perfect match with the primary test surface.

Although the primary and secondary surfaces were very close when I finished grinding, I had deepened the center in the process of polishing and figuring the primary, which caused a concave fit, and the secondary was polished face down on its lap, driving the match even more concave. If you can, polish with the lap on top; it will minimize this effect.

When the center of the secondary was fully polished and the edge was nearly polished out, I took steps to correct the radius. To raise the center, I warm-pressed a star of 0.005" Mylar into the lap. With its center depressed, the lap polished only at the edge of the glass. I kept the outer part of the lap well trimmed, about 1/8" inside the secondary diameter, to prevent a turned down edge and to reduce chipping of the pitch.

As the rings decreased they turned into irregular arcs of a convex match. I then pressed the star out and resumed full contact polishing. (If the star wears out during the correcting process, it should be warm pressed back into the pitch.) The final fringes should be straight and smooth. Do the final testing with only a few fringes, and test the mirror along both diameters. This is a check for astigmatism; if the radii were different along the two axes, one set of fringes would have been curved when the other set was straight. Astigmatism must be polished out or image quality will suffer.

Once the secondary is finished, you can aspherize the primary to its 55% ellipsoidal figure. If necessary, recut any filled or partially filled channels in the full size lap and then warm press the primary on it. To aid in obtaining perfect contact, slightly warm both the mirror and the lap.

To check the correction I used a Couder Screen with four zones. For the figures for the knife-edge shift I calculated the correction for a paraboloid and used 55% of those figures as my zonal targets. I subtracted the central zone figure from the others and also subtracted zone figure from zone figure to find the differences. I tried to hold these differences as well as the zone readings themselves. The numbers for the perfect ellipsoid were 0.000", 0.015", 0.035", and 0.060". The final test readings were 0.000", 0.010", 0.027", and 0.060". The final radius was 299", but the figure was so fine and smooth that I decided not to correct it.

Be careful not to overwork during this final stage. If contact is a problem, try warming the lap and mirror in warm water before working. I also found a thick rouge mixture better during this stage of work. To be sure no temperature effects were present, I allowed the mirror to sit for twenty-four hours before any zonal readings were made. The mirror must be stable before testing, otherwise you will find you are working all around theoretical numbers but never achieving them. After a few nights of working, and most of that time spent waiting, you should be finished. And you should be proud of yourself for making what are probably the best optics in your life. I was.

After it was all done, I sent my zonal locations and readings to Bob Cox. He ran a check of the surface figure using the Stoltzmann analysis from *TM#23*. The greatest deviation from an ellipsoid that touches the desired ellipsoid at both edge and center amounts to only 1/143-wavelength.

Coatings

With four reflecting surfaces, it was obvious that the system would need special coatings if I wanted to have a decent final reflectivity for the system. As the table shows, light loss is severe for regular aluminum.

Percentage Surfaces		Number of Reflectivity		
		2	3	4
Regular Al	88	77	68	60
Enhanced Al	94	88	83	78
Enhanced Al	97	94	91	88
Vacuum Silver	98	96	94	92

Since an overall transmission of 60% is unacceptable, get 94% or 97% enhanced aluminum or, still better and you can afford it, get vacuum-deposited silver with a protected overcoat. After going to the extra work of making superior optics, skimping on the coatings because of some extra cost would be foolish.

The Mounting

By the time I finished the optics it was Christmas. Some weeks earlier I had asked two amateur friends to help with the mounting of the Schiefspiegler. Jim McKinley made the mount base several months earlier. It consisted of a 2" solid polar axle, bearings, and the base to attach to the pier. Jeff Hutton made a fork from laminated red oak 4" thick at the base with 37" tynes and an inside dimension of 20".

I was accumulating parts everywhere, all ready for assembly. The fork was bolted to a 45-pound cast-iron barbell bolted to a 8" steel disk welded to the polar axle. The axle holding the assembly was placed in a Clausing lathe at work, and the outside diameter and front face, where the fork would be mounted, turned true. I finished the mount by adding a large Wolf drive. All that remained was completing the telescope assembly. One small problem slowed the work — I broke my thumb in a skiing accident.

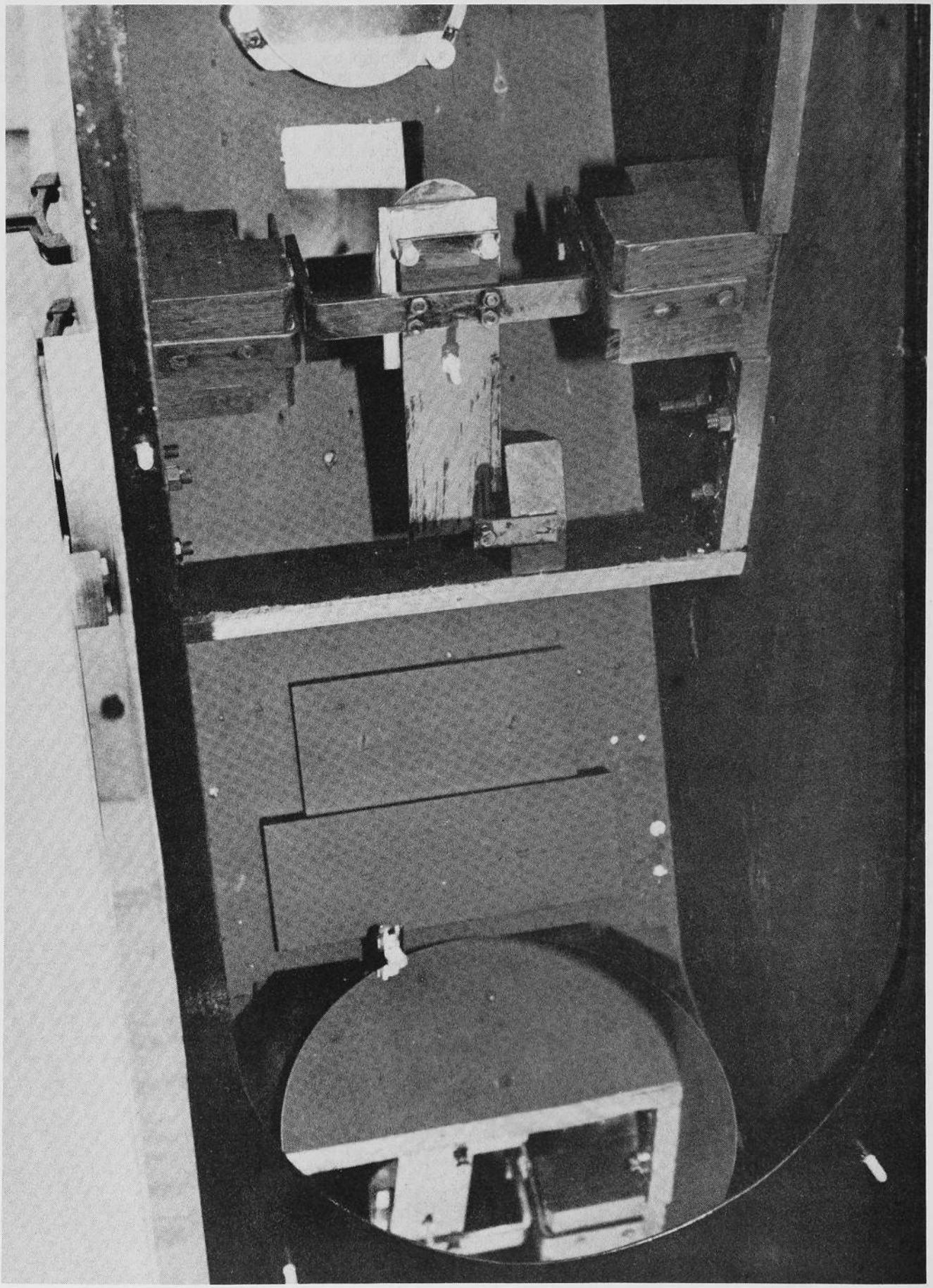
The Tube Assembly

One sunny day in April Steve Rismiller helped me bring home two sheets of ¾" plywood in his truck. That weekend, despite the sore thumb, I managed to cut all of the major tube parts with my table saw. In building the tube assembly I took dimensions scaled from the drawing I'd made earlier. I carefully checked all the angles and dimensions. Sometimes they didn't work out so I had to make a choice. During these times I created more triangles to give me insight as to what was important, always working from the optical axis.

One critical parameter was the location of the optical flat. I wanted to bring the image out in two locations. This element could not interfere with the light traveling from the primary to secondary in either position. Although I mounted it as far as possible from the tertiary, just outside the light path between the primary and secondary, the final focus still lay outside the main tube. In the end I added an extension to the tube to take up this distance. Both faces where the eyepiece holder would be mounted had to be 90° to the optical axis. I made the space between them parallel to the axis of the incoming light for easy pointing at stars.

The flat rotates about a pivot point in the same plane as the mirror surface, otherwise the alignment could be lost when you flip it to another position. Two ¼" x 20 adjustable bolts act as stops for each location. To switch positions I take off the eyepiece holder, reach in, and push the extended aluminum plate from the present mirror location to the other position, letting magnetic catches hold it in place. Then I moved the cover plate from the other position, placed it where the eyepiece holder had been, and then placed the eyepiece holder in the new position. All this takes thirty seconds.

Alignment is critical in Schiefspiegler designs so that the mirror cells are made to lock in position with nuts on both sides of the base. For portable telescopes, Bob Cox's push-pull type design (see *TM#6*) is best for preventing movement of the mirrors. I left long bolts on the cells so the mirrors could be moved back and forth to change the



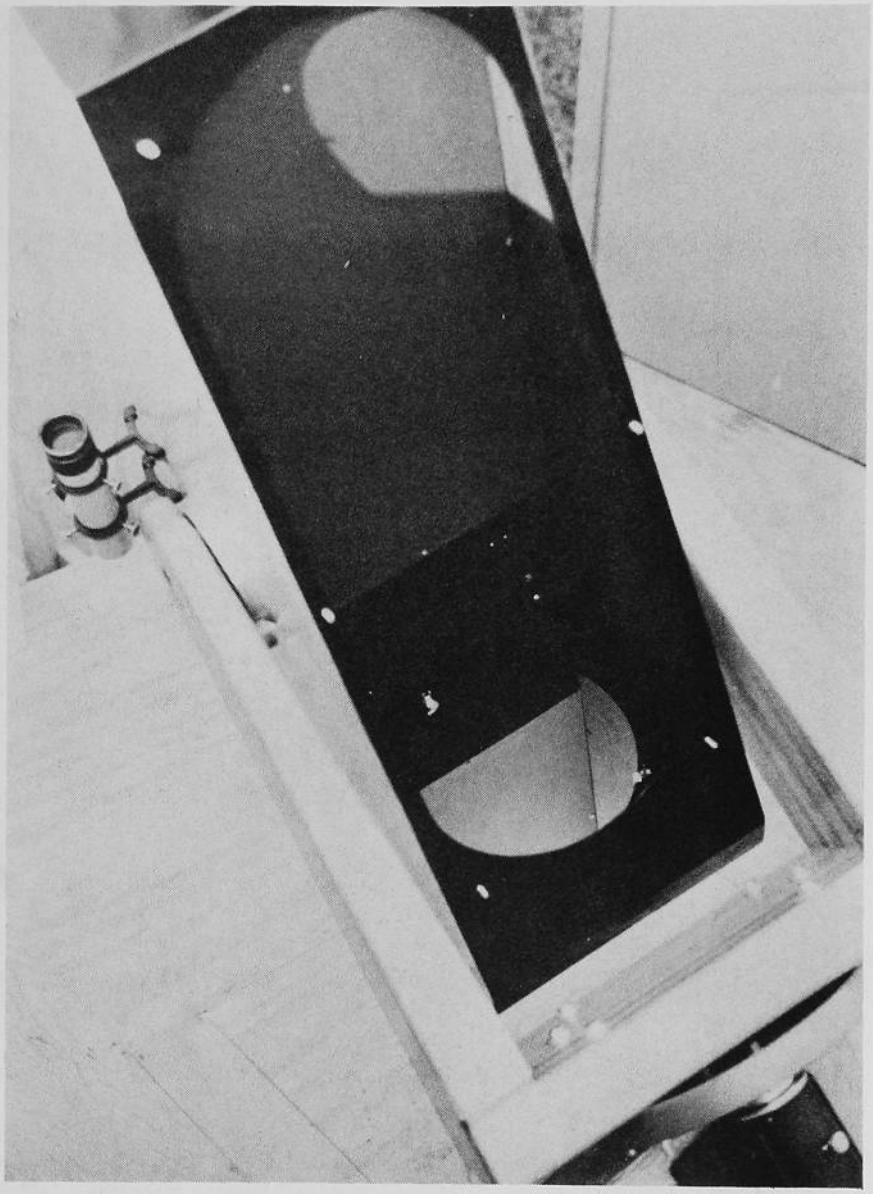
mirror spacings or to adjust focus. This is advisable in case you've made a mistake and the final focus does not come out where you expected it to. I did recalculate the mirror spacings to account for the slight radius differences from design and incorporated the new dimensions in the final drawing. I allowed the primary mirror to move up and down 1.5″ in its cell in case I decided to adjust the angle to the secondary. However, it was not necessary to adjust it since the performance was just fine at the design location.

To balance the tube assembly I placed unfinished mirror blanks in the cells and then mounted the finder and eyepiece holder. I rolled the tube on its side on a golf ball to find the balance point. It then became apparent that the tube would not clear the fork base, so I had to cut 4″ off the back of the tube assembly. Expect to make some mistakes and be prepared to fix them. You are not building a Newtonian!

The declination bearings are two slices of secondary aluminum tubing with wooden disks inside. They are bolted to the tube sides and ride on Teflon pads attached to the fork. This method is simple to use and works very well. I did have to add steel weights to the tube to account for some balance differences and to fit the fork. It is not simple to get this instrument to balance for all sky positions. Mine took a little adding and subtracting of weights to achieve final stability.

The observatory — completed the summer before — is 12′ by 12′ and stands two stories high. It is built on a hillside with a 20° slope which made it difficult to wheelbarrow cement some 300′ from my driveway. All the wood also had to be carried out to the location. The construction is post and beam with a plywood covering and is painted green. To control temperature in the observatory during daylight hours I placed 3.5″ fiberglass insulation in the roof, and in the south, east, and west walls. It has worked very well and was worth the effort.

The sliding roof exposes the whole sky for observing when it is slid completely out of the way. The extra story under the observing floor raises the telescope higher off the ground and also serves as a storeroom. The pier is about 9′ high and rises about 18″ above the observatory floor. I poured a concrete angled top to attach the mount base. The remainder of the pier is concrete blocks.



With the main light baffle removed, the tertiary mirror at top reflects light to the flat upper center and then out to the eyepiece holder, which is not mounted in this picture. The optical flat is mounted on a long piece of aluminum that acts as a guide touching the stops. The 12½″ primary is at the bottom. Bolts on the outside are to hold the cover on when the 'scope is not in use.

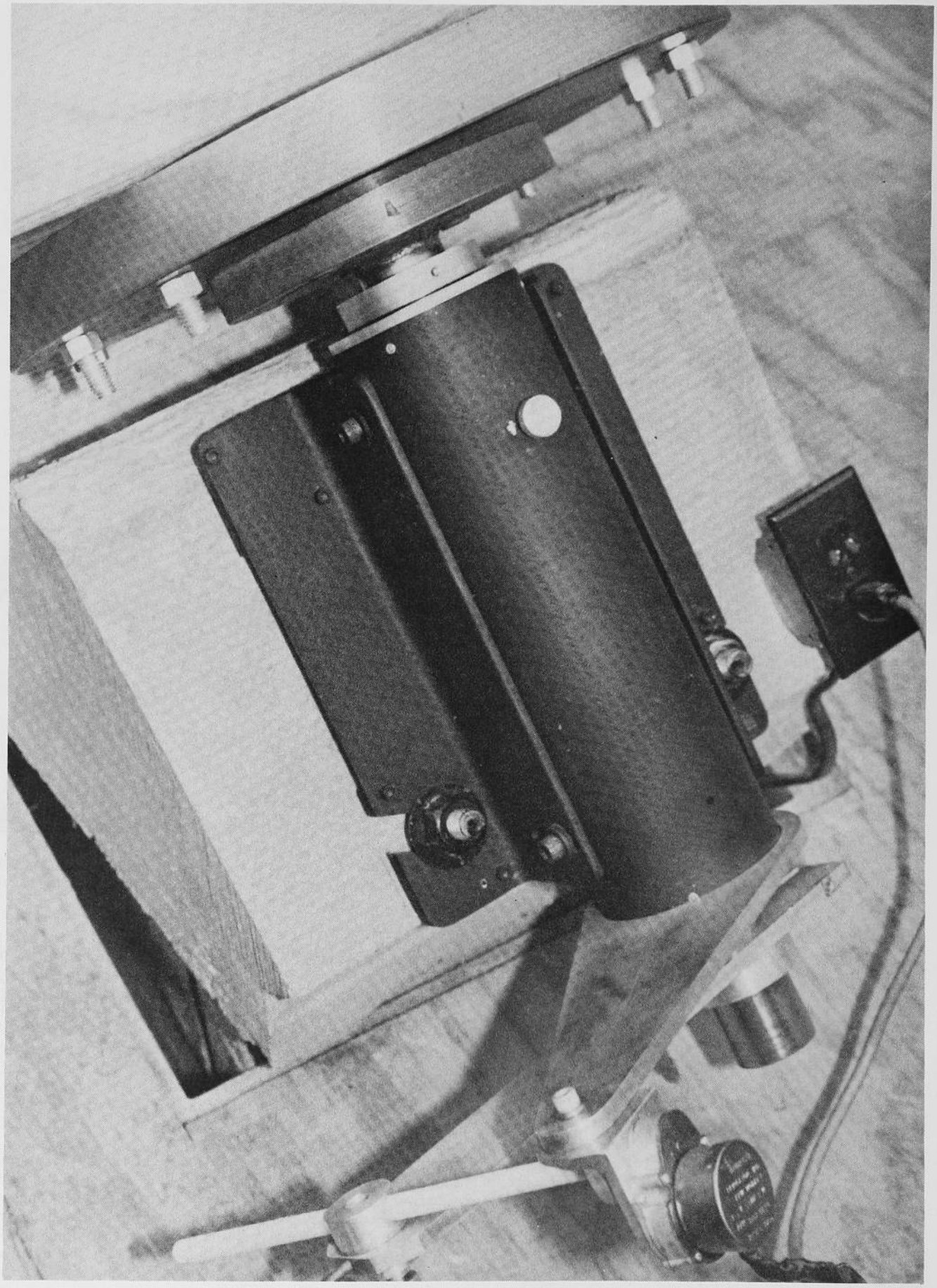
The front of the telescope with the light baffle in place. Note the oak fork and barbell that the fork is mounted on.

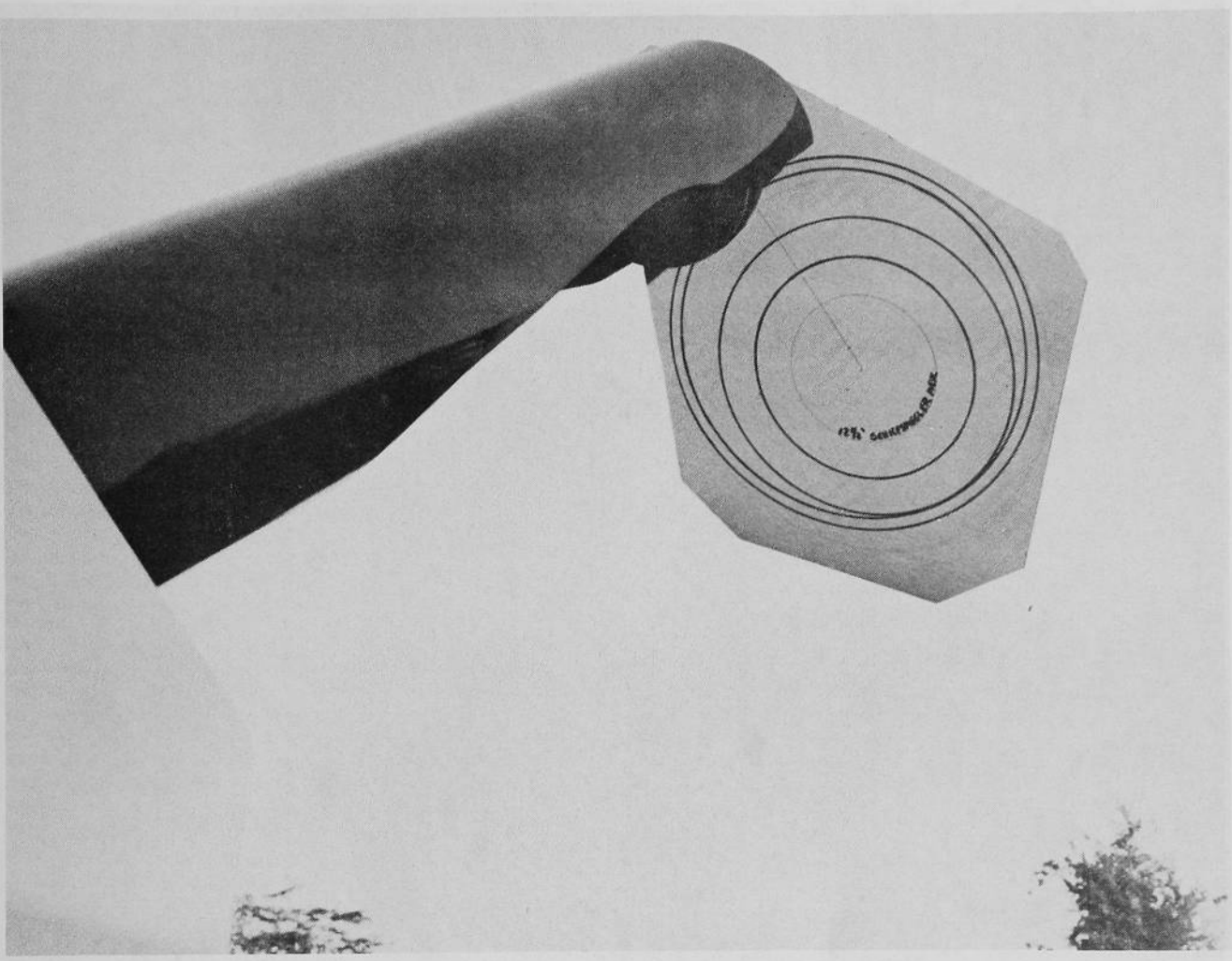
First Light

It was May 26, 1984, and I was busy mounting the tube on the fork and putting the optics in their cells. At 9:30 that evening I lined the instrument on Mars using the alignment corner of the tube. I placed a 25mm eyepiece (254x) in the eyepiece holder, focused, and saw a very high-contrast, detailed image of Mars, but with a little smear below it. I had yet to make an alignment mask for preliminary alignment of the system and had just "eyeballed" the optical alignment. I was elated and went back and adjusted the primary and secondary on a star to remove the smear and the slight astigmatism apparent in the image. Stars are the best test objects for final tweaking.

One of the first tests I wanted to perform was for the image tilt of 9°. With Mars I could detect a focus change when the image was shifted from the top to the bottom of the field, but on the Moon I could not see any shift in any of my 1.25″ diameter eyepieces. The Moon is spectacular with a 20mm Erfle eyepiece at 318x. I switched to 2″ eyepieces. With a 72mm Kellner there was no shift visible, but with a 32mm Erfle the shift was there.

I then modified the 2″ adapter by cutting the half angle of 4.5° and rotating the parts for the 9° angle. I epoxied them together, sanded, and repainted the adapter. In doing this, it is important not to tilt the eyepiece holder to adjust for the tilt since that





The primary alignment mask is in place mounted on the secondary cell bolts. The two large circles are used to align the primary.

would throw the eyepiece considerably off the optical axis. The idea is to tilt the eyepiece relative to the optical axis. For an example of the construction of a tilt correction adapter, see *TM#4*, page 13.

The adapter was not a big sucess. I found that the 32mm and 72mm eyepieces vignetted the image severely. Obviously these eyepieces are not designed to be used at a tilt. I normally use a straight focuser since the slight field tip visible in the 32mm Erfle is tolerable. For photography at the focus a tilted adapter would be necessary.

I observed all of the summer of 1984 for the A.L.P.O. During the first two weeks in June I did eight drawings of Mars before the Martian dust storms and poor summer seeing came. Whenever the seeing was good Mars showed considerable detail. Other observations proved to be fantastic. The rings of Saturn were split into several divisions, more than I had ever seen, while the Moon was detail upon detail. Unfortunately, most of the summer had poor seeing, which limited the telescope except during occasional minutes of good viewing. One evening I was looking at Jupiter low in the southern sky. I started viewing with 158x, and since the seeing was good I tried 227x, then 254x, and finally 318x. I could see one of Jupiter's satellites near the preceeding limb. It was so clear that I started looking for surface detail on it. Seeing none, I scanned the planet itself, but — just that quick — the seeing turned bad. I can't wait until the planets are high in the sky to observe them again.

The mount base with the Wolf drive. The 45 lb. barbell to the left has the fork mounted on it. The polar axis can be adjusted by raising the back of the polar axis housing. The two Allen bolts on the ¼" angle-iron base sides are to lock it in place. The two large bolts in the base bottom are for azimuth adjustment of the polar axis. A third bolt under the front bearing acts as a pivot.

The telescope is also excellent for deep-sky viewing, which was a very pleasant surprise. My 72mm eyepiece gives 88x and the 32mm gives 199x; both have 2" diameters, and for deep-sky work they are excellent. The Buchroeder Schiefspiegler is baffled in the secondary tube to let no stray light in, and the inside mirrors are all enclosed in light tight boxes so no stray light enters the eyepiece. In this respect it is better than a Newtonian or any other telescope I have ever used. The images show it, too. The contrast is superb and, of course, the definition is there and the field is flat even though it's slightly tilted. A few days ago I was observing the Ring and Dumbbell nebulae with the 32mm and 72mm eyepieces. With both eyepieces the images were superb and had excellent contrast even though the First Quarter Moon was in the sky. Not bad for living less than three miles from an expressway.

The telescope is now painted — the completion of a twelve-year project. Building an instrument of this complexity and size requires very detailed planning and much perseverance. If you succeed, you will possess one of the finest telescopes that can be made.

Richard J. Wessling
5429 Overlook Drive
Milford, OH 45150

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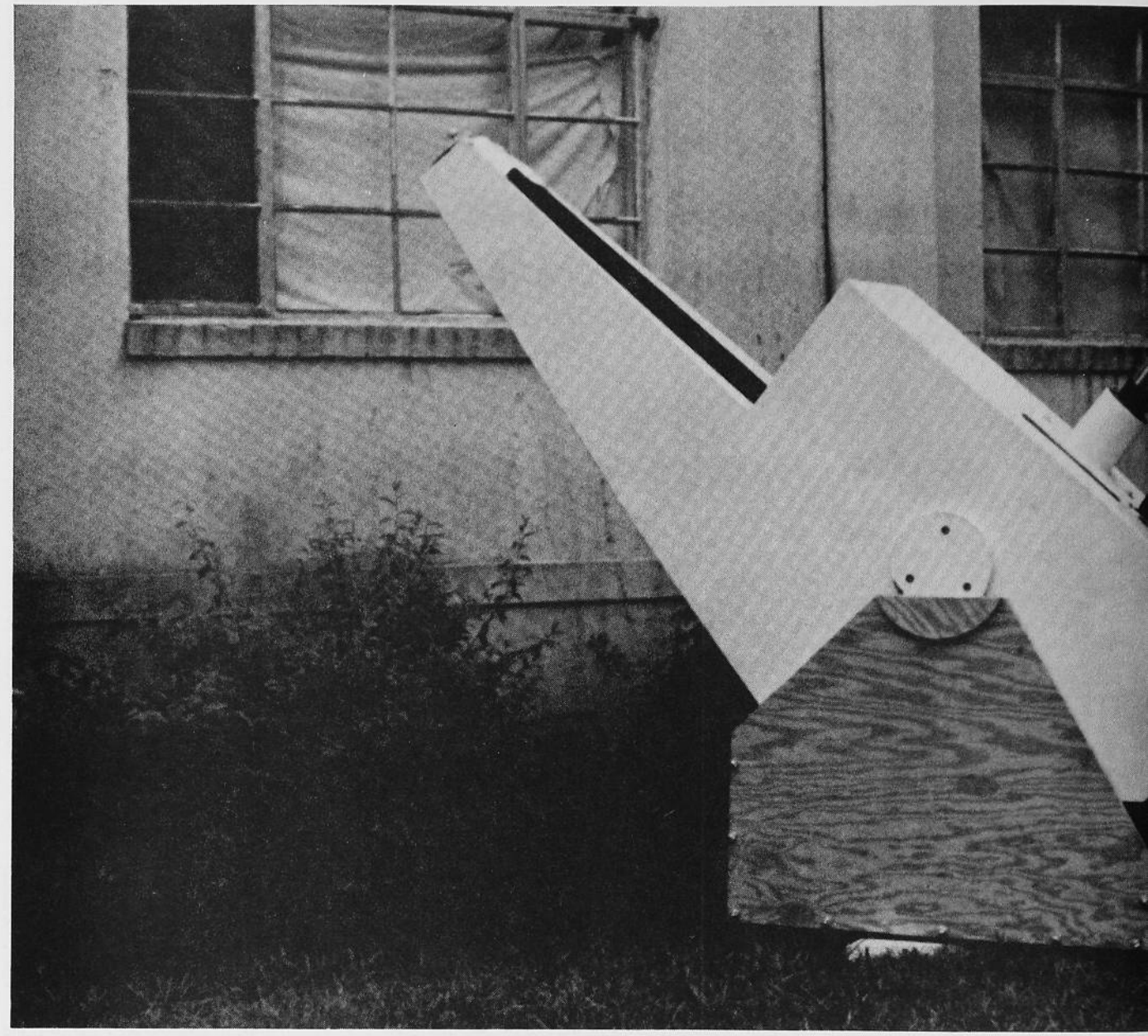
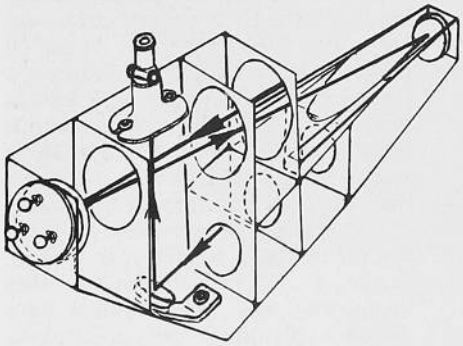
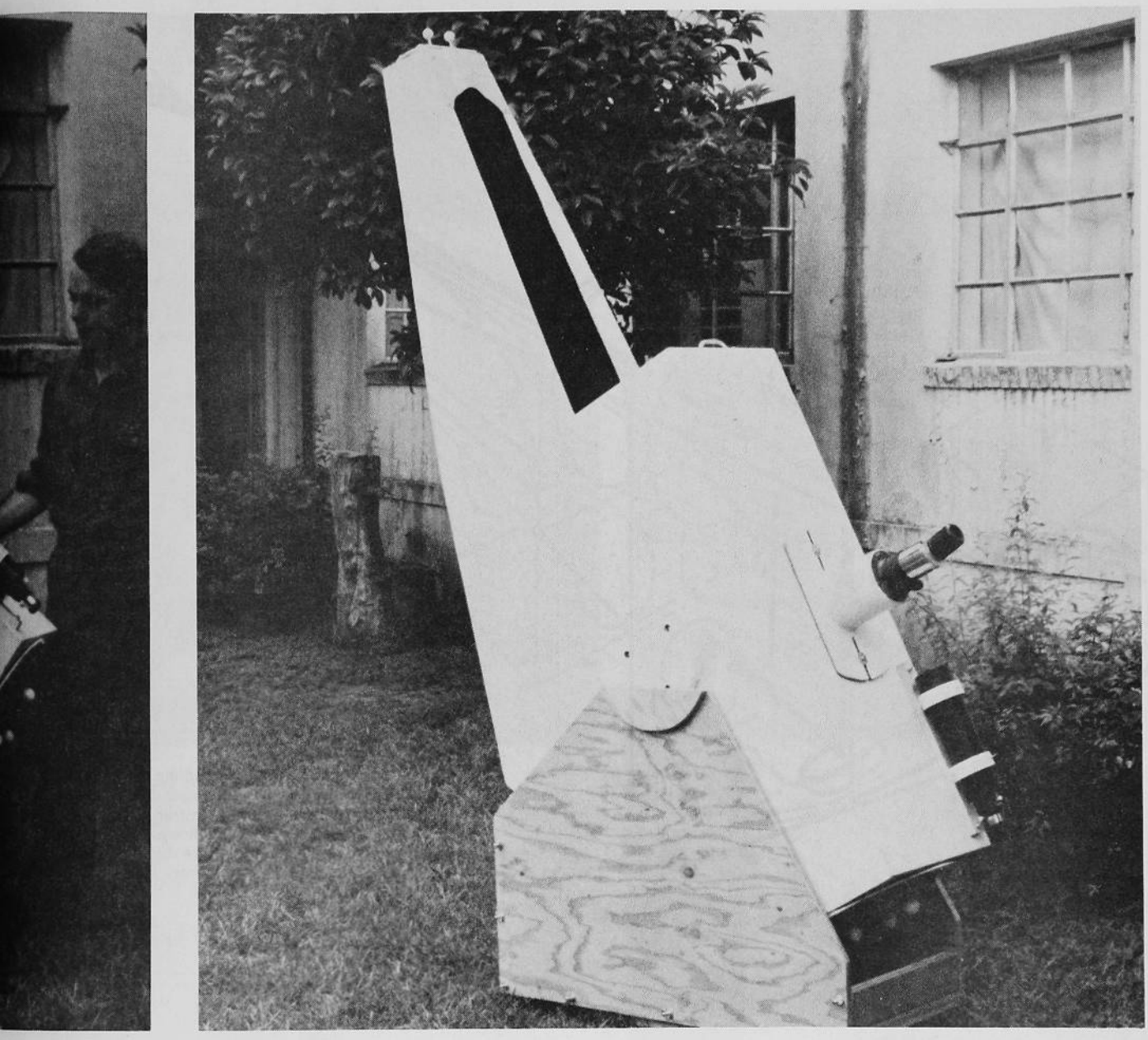




Construction of a Second 12.5″ TRI-SCHIEFSPIEGLER



Although the shape is awkward, the tube is light enough for one person to move about. I carry the rocker fully assembled on a dolly when I'm alone. Here we see me with the telescope pointed in a neighbor's window.

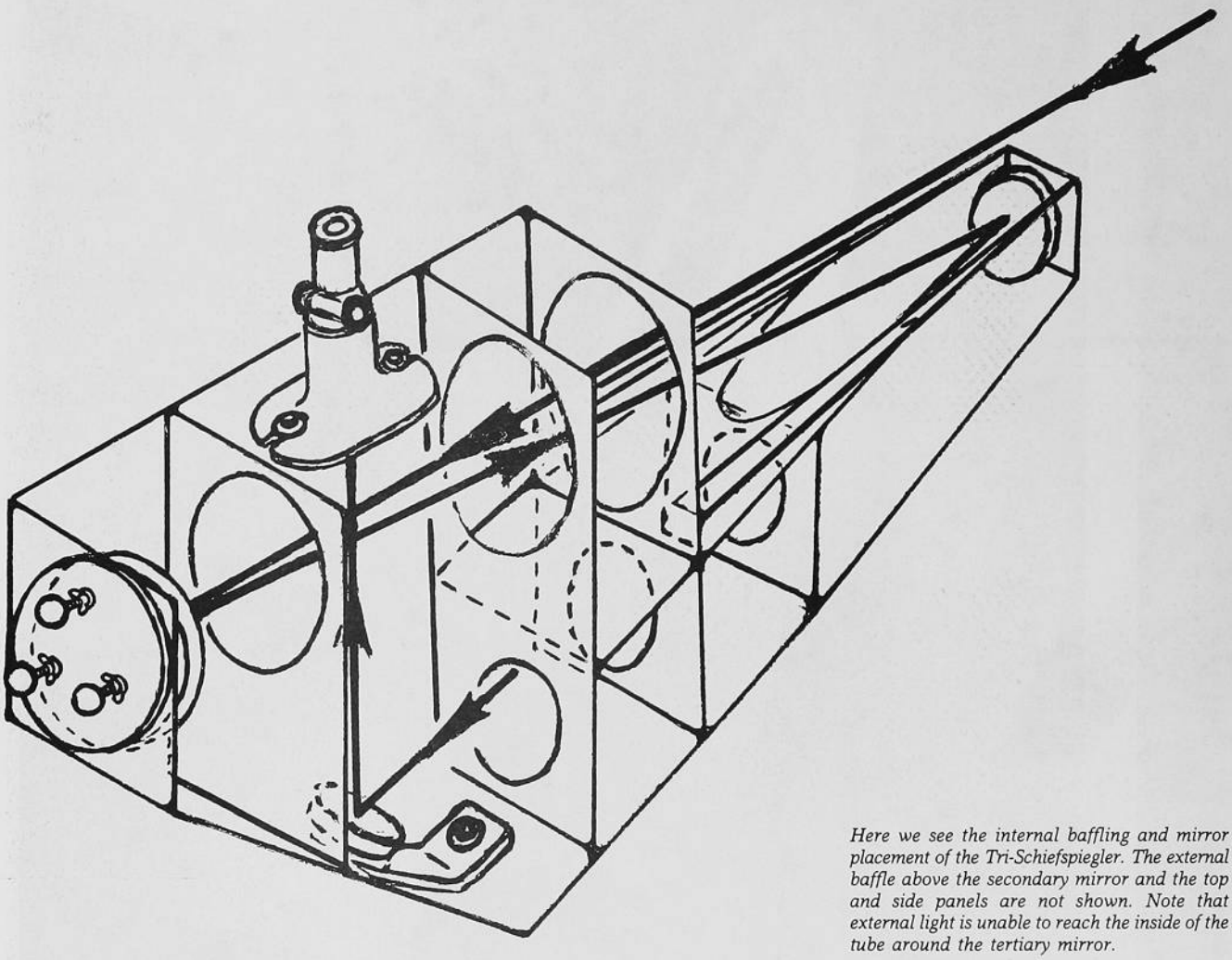
The eyepiece is easily accessible for objects high above the horizon.

The lack of published and tested designs for large tilted-component telescopes has probably discouraged many TMs from constructing them, despite their famous performance for lunar and planetary observing at smaller apertures. The Kutter Tri-Schiefspiegler design is reported to be inadequate above 8″ aperture. However, just recently Richard Wessling constructed a successful 12.5″ Tri-Schiefspiegler using an improved design by Richard Buchroeder. Although I am a telescope maker with only moderate experience and am dependent on handtools and homemade equipment, I found construction of my own 12.5″ Buchroeder Tri-Schiefspiegler quite straightforward.

Optical Fabrication

It is said that the success of a tilted-component telescope such as the Tri-Schiefspiegler depends upon optical surface smoothness (lack of micro-ripple), precise surface curves, and close adherence to the specified radii of curvature. Surface smoothness and precision was achieved by using a soft, well-trimmed, well-pressed lap with short, slow strokes during final polishing. Although I simply used very dilute cerium oxide at this stage, other workers might prefer red or black rouge. Testing the mirrors is simplified by the fact that they all can be null tested without auxiliary precision optics. A simple homemade spherometer was quite adequate for getting the radii near specification during rough and fine grinding. Because of the long radii, a good deal of adjustment was possible during polishing. Final radius determinations were made by the Foucault test.

The prospect of Foucault testing the long-radius tertiary mirror outdoors should not intimidate anyone, even a lone worker like myself. First attach the light source and slit to some solid object at the specified distance from the mirror. The mirror stand should be strongly constructed and firmly



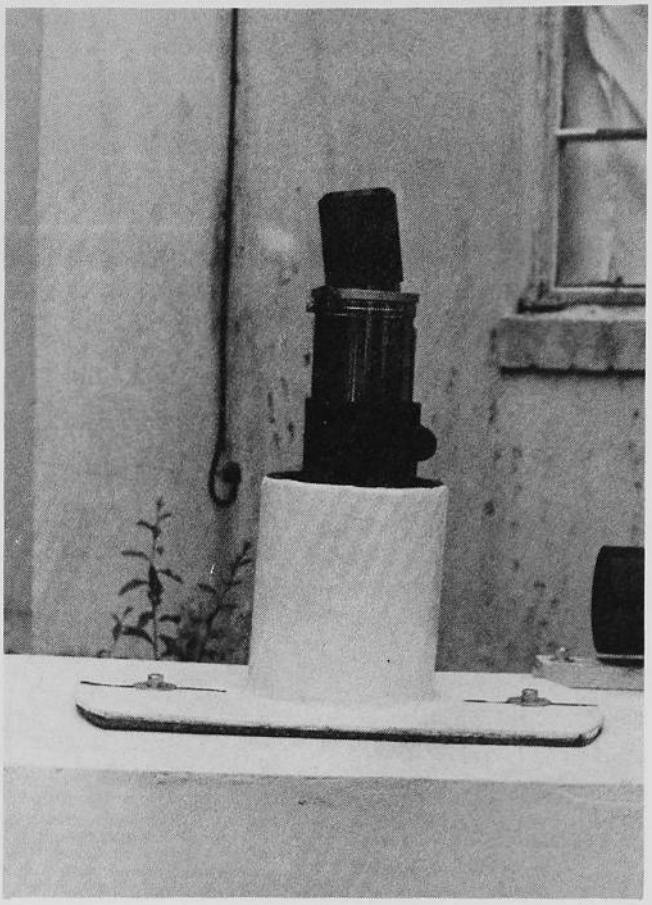
Here we see the internal baffling and mirror placement of the Tri-Schiefspiegler. The external baffle above the secondary mirror and the top and side panels are not shown. Note that external light is unable to reach the inside of the tube around the tertiary mirror.

clamped to something solid. Spring-loaded screws for adjusting the mirror tilt in both altitude and azimuth will greatly simplify mirror alignment. You quickly learn how much to turn each screw to shift the optical axis a given distance back near the light source.

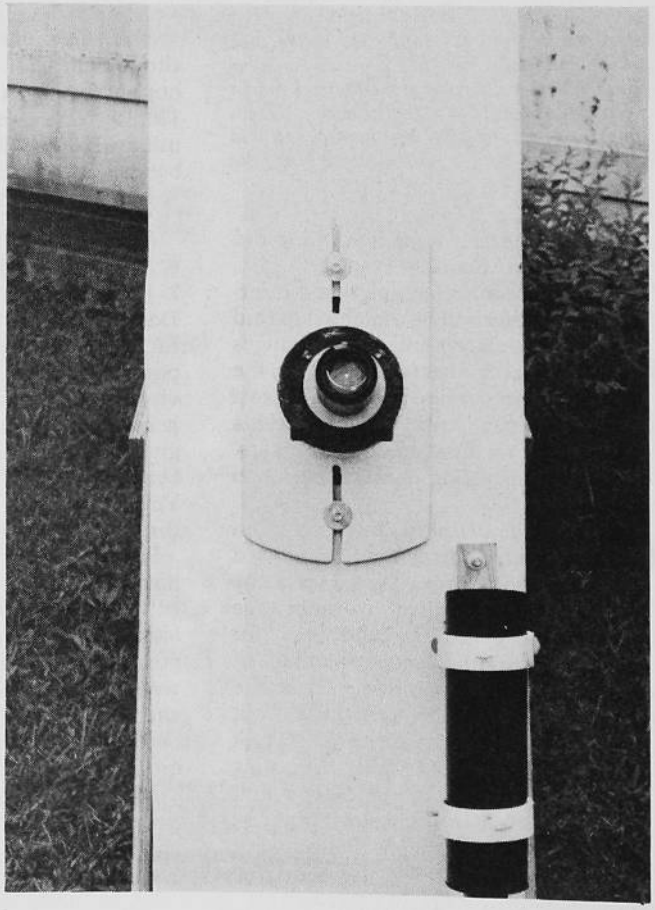
To get the optical axis of the mirror to pass near the light source, you only need a flashlight. Locate the optical axis from a position near the mirror stand. Adjust the mirror tilt to get the axis aimed roughly in the direction of the light source as viewed from that position. Repeat this procedure from a position somewhat farther from the mirror. Keep working back toward the light source until you reach it. It only takes about ten minutes (and a bit of walking back and forth) at the beginning of a night's testing.

During subsequent tests, place the mirror in the test stand in exactly the same position as before. The position of the optical axis will shift just a few inches at the light source distance from test to test. Locate the optical axis of the mirror using the flashlight as just described. The image of the slit will appear opposite and equidistant the mirror axis from the illuminated slit light source. While viewing the mirror with binoculars, move laterally and vertically near the estimated return light beam position. When the mirror suddenly appears lighted, you've located the returning light beam. Place a small tripod-mounted telescope in that position and observe the illuminated mirror. For all but the final Foucault test, any straightedge held by hand in front of the telescope can serve as a knife-edge. If the mirror has any zones, the telescope and/or knife-edge may have to be shifted back and forth several feet to measure their radii. Don't be too concerned about the condition of the mirror edge — in the Buchroeder design the tertiary is oversized.

During interference testing of the secondary be sure that the viewing position and the monochromatic light source are very nearly perpendicular to the back of the mirror. If they are not, you may get inconsistent readings while you're trying to get the secondary and test plate radii to match. Start testing as early as possible while polishing so that the radii can be matched by polishing with the tool or mirror on top, rather than using a pressed Mylar star. Pressed Mylar patterns change the mirror radius relatively quickly, but they cause

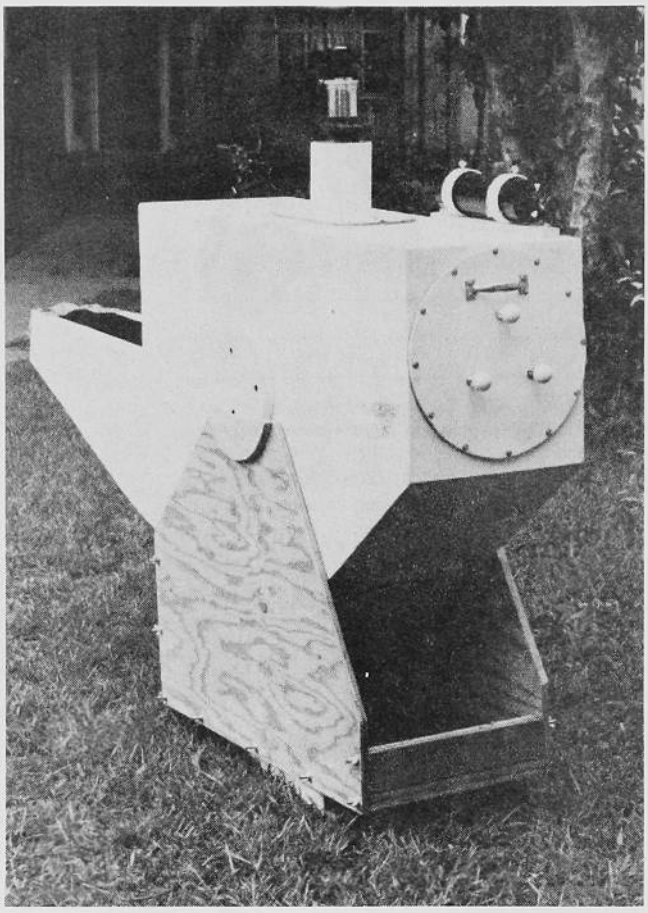


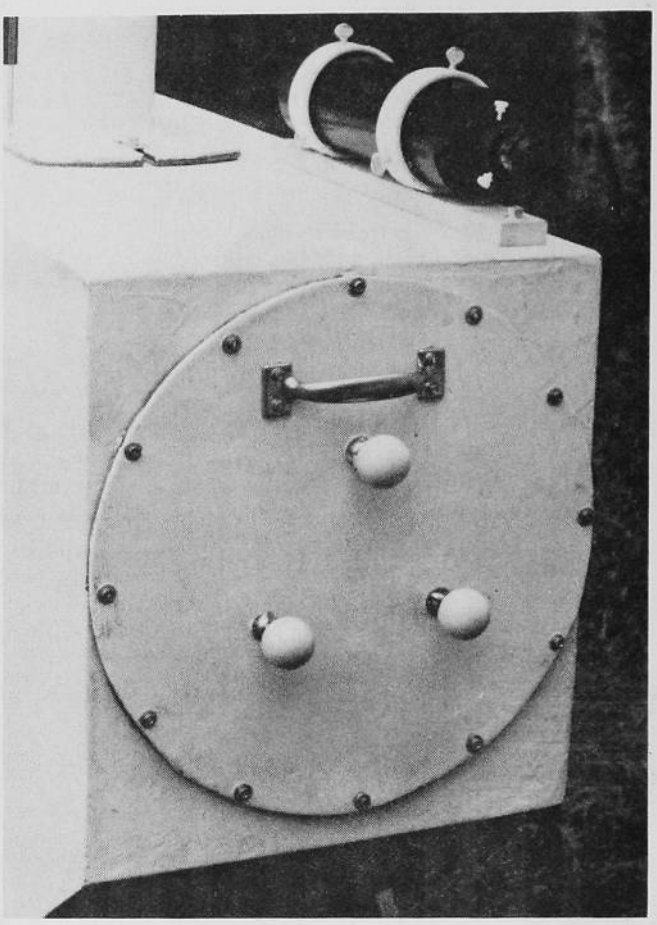
Looking down the tube, we see reflections from all three mirrors. The small circle of light seen in the secondary is light transmitted through the eyepiece.



In this close-up of the focusing mount, the tilt of the eyepiece is readily seen. Note that the tilt is toward the front of the telescope, rather than toward the back, as it is in Wessling's four-mirror design.

Looking straight down on the focusing mount, we can easily see the 9° tilt of the eyepiece. The rack and pinion focuser mount is a large Jaegers model. The tilt is built into the 2" adaptor, so no vignetting occurs.





The rear mirror cell is attached to the tube assembly around it by a fiberglass cell mounting plate. Note the collimation knobs and windnut lock nuts, per A. L. Woods. The mirror, its cell, and the mounting plate can be removed and replaced without greatly disturbing the collimation.

aspheric figures, or at least they did when I used them.

Workers unaccustomed to interference testing will be delighted to find that the displacement of the fringes gives a direct measurement of the surface errors, unlike the Foucault test in which the knife-edge positions correspond to the slope of the errors. Interference testing is much easier to interpret.

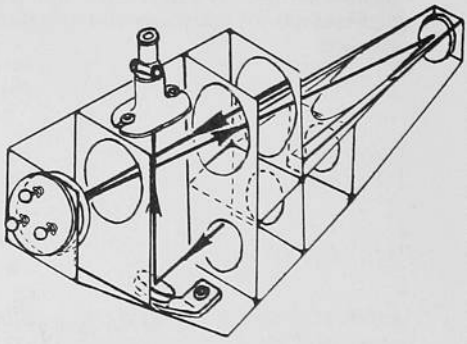
Since the primary mirror is an ellipsoid with a correction 55% toward the parabolic, it could be null tested by placing the light source and knife-edge at conjugate focii (179.6″ and 1,161″ for the 12.5″ design). Because the image of the slit will be magnified 6.7x at the conjugate position, be sure that the slit is much narrower than usual so that contrast is not lost. As Richard Wessling did, I chose instead to use the Foucault test at the primary's radius of curvature. The correction is so slight that it is very easy to over-correct, so use short figuring spells and test often. I recommend the Ronchi test for checking for DTE, but not for checking the overall curve. The correction is so weak that even using a 150 line/inch grating, the Ronchi bands appear almost straight.

Mounting

After seeing the photo of A.L. Woods' 6″ Kutter Tri-Schiefspiegler in *TM#10*, I decided to mount my telescope Dobsonian-style and to omit the flat that Richard Wessling used to shift the focal point of the Buchroeder design. For viewing objects more than 45° above the horizon, the original three-mirror design gives an eyepiece position that is quite convenient with a Dobsonian mount. You sit or stand and look down, as if through a microscope.

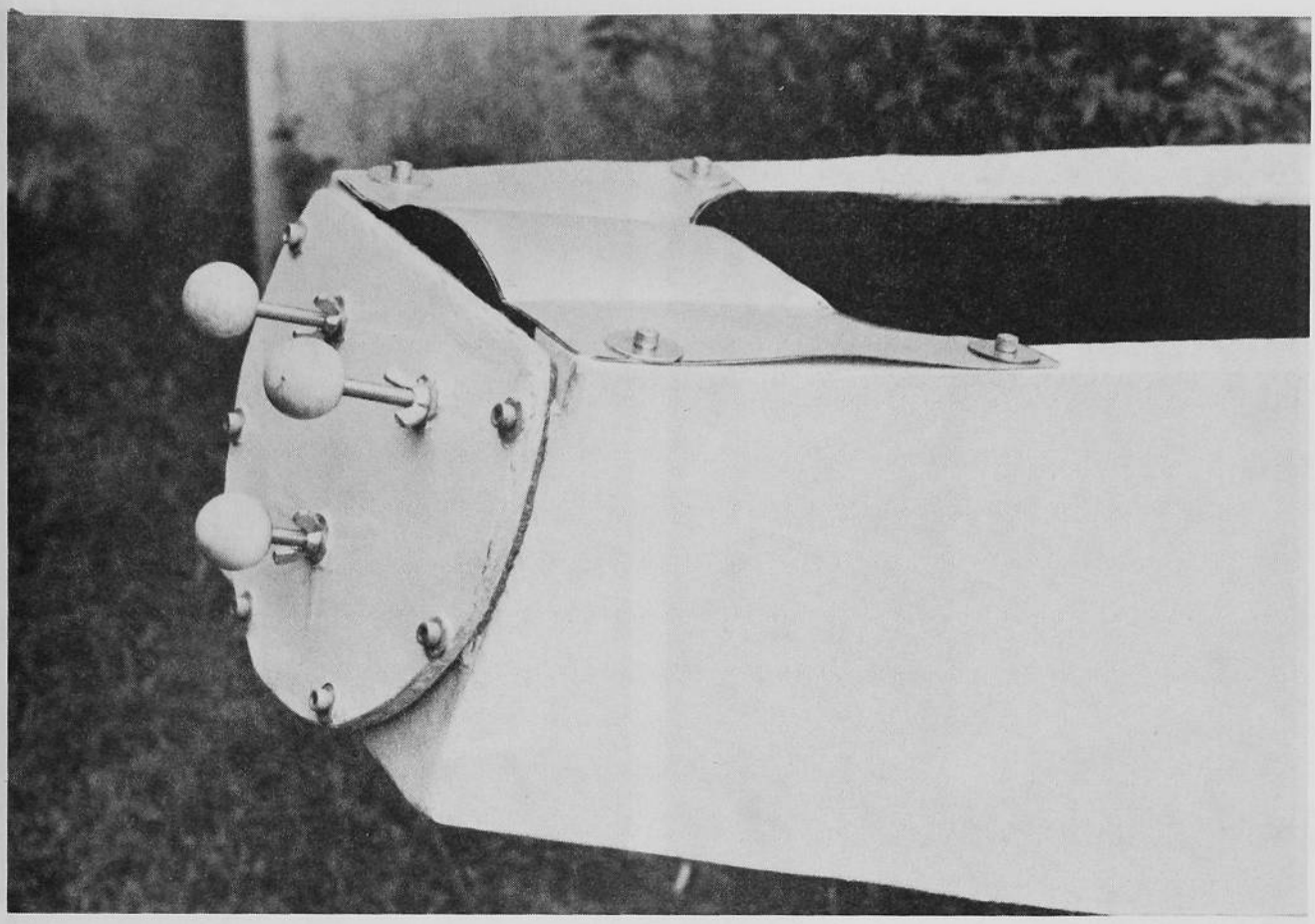
For viewing objects closer to the horizon, you have a choice between using a star diagonal or standing on a ladder and bending down over the eyepiece, an uncomfortable position. This would be much less of a problem with smaller apertures because you could bend over the eyepiece while standing on the ground at all telescope positions.

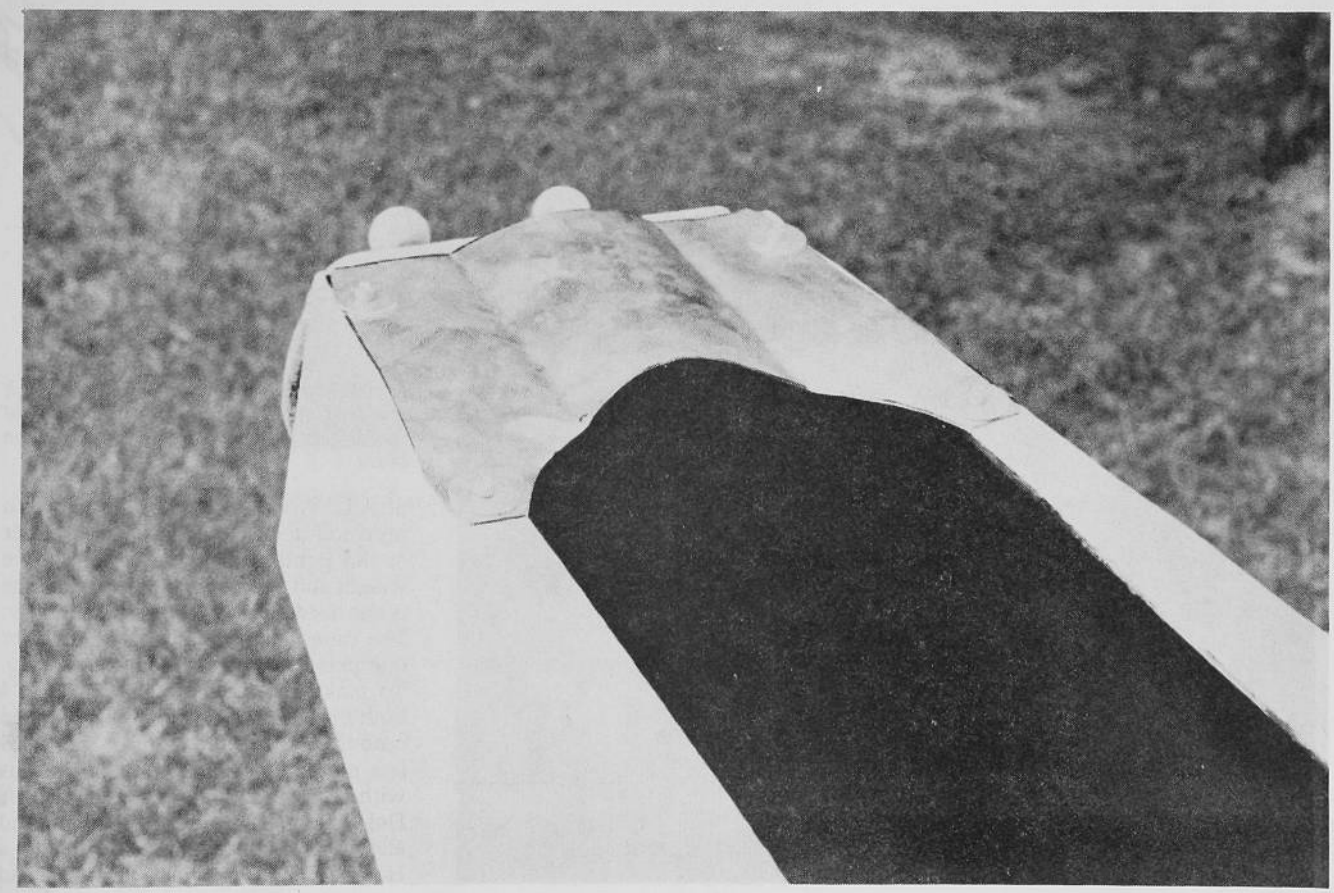
If the original eyepiece position (i.e., three mirrors and no flat) is used with an altazimuth mount and an equatorial platform to track the stars, it should be as low as possible to keep the eyepiece easily accessible. Note that removing the flat also causes the 9° tilt of the focal plane to be in the direction opposite that shown in Wessling's article. The tilt is in the same direction as that shown in A.L. Woods' sketch of a Kutter Tri-Schiefspiegler in *TM#16*.



I found the Dobsonian mount and equatorial platform easy to construct, requiring no counterweights or machined parts. The tube is an adaptation

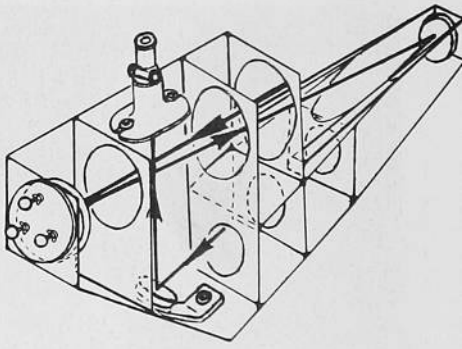
The secondary mirror cell also bolts to the tube assembly via a fiberglass mounting plate. Note the thin metal external baffle above the secondary. This shields the tertiary from skylight passing just above the secondary.



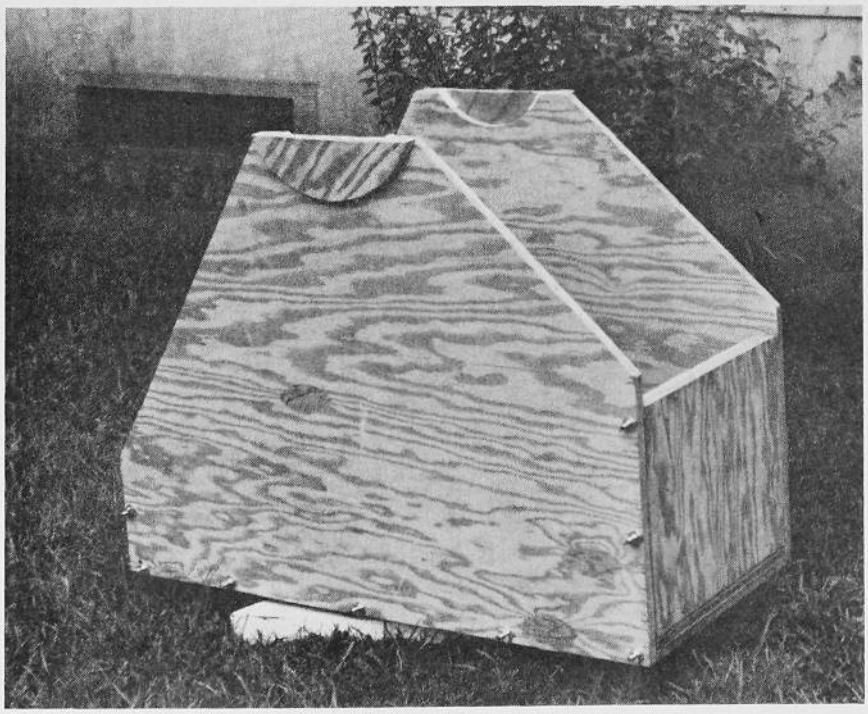


The side and front boards are ¾" plywood, and the bottom board is double ¾" plywood. The side boards bolt onto the front and bottom boards via long stud bolts that run through the width of the rocker. The front board attaches to the bottom board via a piano hinge.

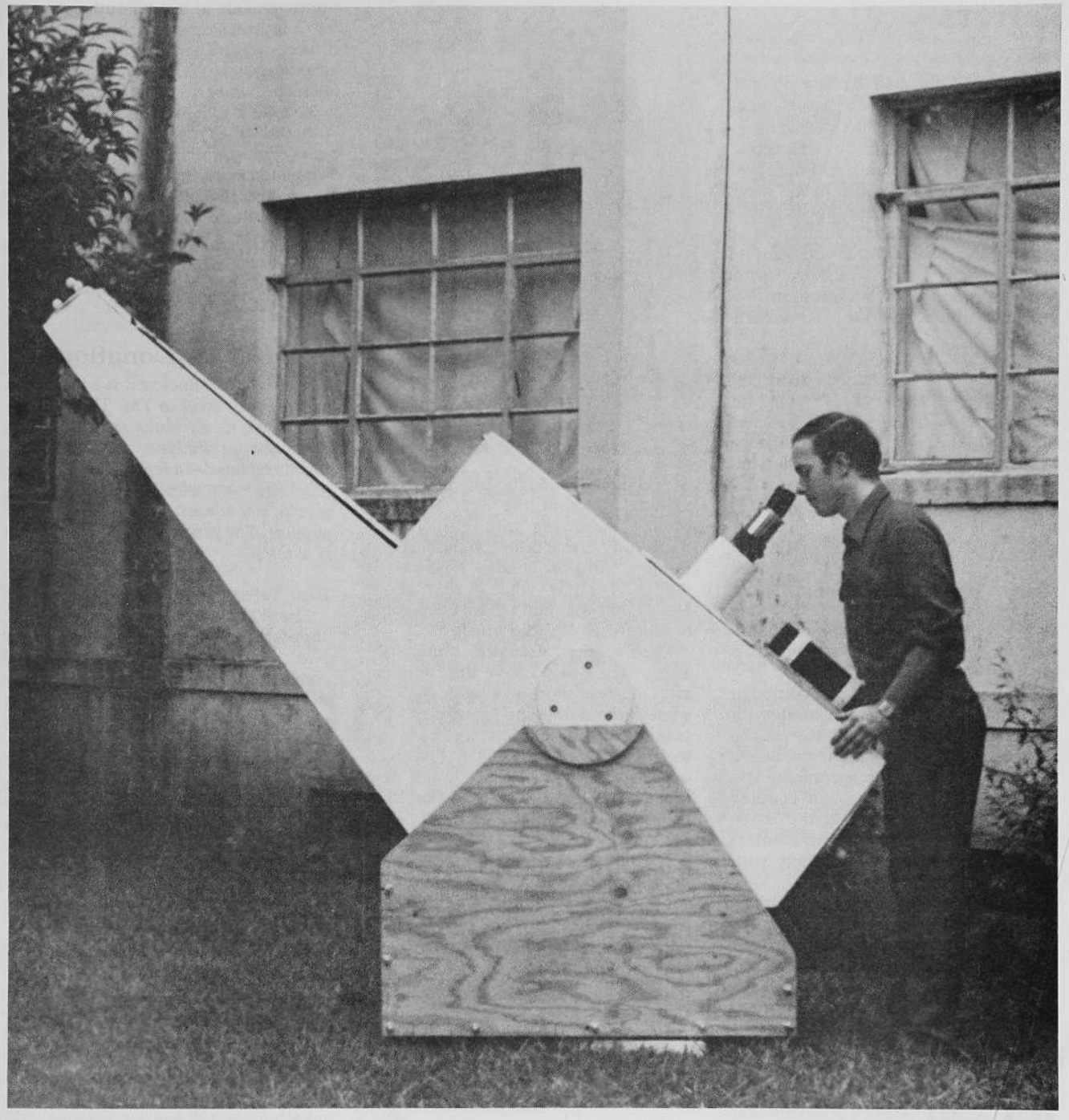
When I was drilling the long holes to take the 5/8" stud bolts, I found the ¾" plywood too thin. The bit would wander and break through, so I reinforced the bolt hole loations on the front board with ¾"-thick boards.



For transport, the side boards completely unbolt from the bottom and front boards, then the front board folds down almost flat on the bottom board.



of A.L. Wood's fiberglass-coated thin plywood design. I omitted one corner of the pentagonal box design to save weight and space. That part of the tube is not needed for light baffling anyway. The tube assembly is light enough for one person to carry about and set up. To make the mount truly portable, I built the rocker with side boards bolted onto the bottom and front boards. This lets me collapse the whole rocker (as with Dan Raether and Carl Blue's Dobsonian described in *TM#16*) and allows the telescope to fit inside a Honda Civic with just the rear end



sticking slightly out of the back. The type of mirror mounts described by A.L. Woods allow the instrument to be moved about and still stay in collimation.

The altazimuth mounting will ride atop a Pursell Platform. At the time of writing, however, it was not working yet, because I'm having trouble with the drive circuit for the stepping motor that drives the platform.

Performance

Collimation was easy and straightforward as described in *TM#16*. I finished the telescope just in time to see Mars during the 1986 opposition. Mars, Jupiter, and Saturn all appear in finer detail than I have ever seen them with the 11″ Clark refractor at the LSU campus observatory nearby.

Last night (August 17) I saw Diemos though moonlight interferred. To do this, the eyepiece had to be adapted with a thin sliver of black tape across the field stop to occult the image of Mars. The lack of diffraction and light scattering in the Tri-Schiefspiegler make such a difficult observation possible.

Saturn simply looks 3-D. I think I could just make out "spokes" on the inner ring on two nights. The moons of Jupiter are easily resolved into disks, but the seeing hasn't been good enough to make out any markings yet. Jupiter itself at 600x has to be seen to be believed.

The construction of the Buchroeder Tri-Schiefspiegler design is well worth the effort.

Steven W. Johnson
127 Clara Drive #2
Baton Rouge, LA 70808

■

Letters

◄3

Number Three. Ad-Libs Astronomics is a new entry here. If you like products from Meade, TeleVue, Celestron, Coulter, Questar, Lumicon, University Optics, Edmund Scientific, Bausch & Lomb, or anyone on the new "good guy" list, but prefer dealing with one source, this is the place. Inventory is the name of the game here. If you want it, they probably have it in stock, with discount pricing. Have a question? No problem there, either. Top-notch catalog.

Honorable Mention: Astro-Physics/ Roland Christen — This is a good guy on the move. Upward. Do you like crisp, color-free planetary images? Roland's apochromats are probably unsurpassed for quality at reasonable prices. For my next telescope. Refractors are alive and well in Rockford, Illinois.

The rest of the list is as before: Lumicon, University Optics, Coulter Optics, Vernonscope, Orion, Telescopics, and Willman-Bell. No one dropped off the list. No one back-slid. But one moved up, and two new "good guys" entered near the top.

I've been fortunate so far. Although I've done considerable business with companies I haven't included on the good guy list, I haven't truly had a "bad" experience. Average quality and average service, even when coupled with low prices, won't make the list, so the others won't show up here unless I have more favorable dealings with them.

And there is one last "good guy" — *Telescope Making*, which keeps us informed of the latest trends in telescope making, prints letters of our personal experiences, and encourages us to try things we wouldn't have tried before.

I'm Enclosing the photos of the Dobsonian mount I made for my Celestron Comet Catcher, for instance. It works beautifully! But I'd have never tried it without your guidance. It's designed to be used by an observer seated in a chair for comfort. The eyepiece is always readily available to the seated observer, whether the tube is in the horizontal or vertical position, or anywhere in-between. Action is smooth in altitude and azimuth, and best of all, no shakes and wobbles. Phototripod users, eat your hearts out! I planned the mount on a Saturday and made a list of materials. I purchased the materials the next day. The Teflon I had left over from another project (I still have lots — a square foot of Teflon goes a long way

— probably enough for ten more mounts). I spent the next Saturday sawing, screwing and gluing (not necessarily in that order), and filling and sanding. And on Sunday I painted it orange. I know what I said about Meade, but you didn't think I was going to paint it BLUE, did you?

Keep up the fine work. I anxiously await each issue. I have the complete set. Let's hear more on eyepieces! Score some more points for "good guy" Dr. Jack Marling of Lumicon for the tip on the star diagonals in *TM#25*. I received one just like this with my brand new Meade 2120 LX-3. The fix works! Now the diagonal is as fine as the rest of the system.

I'd like to close with a plug for a product any Schmidt-Cassegrain owner should seriously consider buying — a Moto-Focus from Jim's Mobile. It makes all the difference in focusing sharply by eliminating vibration.

Jan M. Owen
9007 W. Clarendon Ave.
Phoenix, AZ 85037

— It's nice to see somebody saying positive things for a change.

Improvements for Simplicity

Dear Richard / In 1910 I saw Halley — and the false one as well. I was eight years old.

But I could not see it this year, though a sixteen-year-old kid was able to see it all the possible nights with either my Comet Catcher or an 8" f/6. The mirror was ground by Mrs. Bombois, the science teacher, and her pupils, among them the kid (Fornez). I helped them with the mount.

By the way, I've made some improvements in my azimuthal mount for Celestron Comet Catcher that made it more solid. There are absolutely no vibrations now. The overall size of the telescope, when it's folded for transport, is 30 x 30 x 60 cm. The total weight, with the tube, is about 10 pounds. I believe in simplicity. For instance, I eliminated a driving screw for altitude. To change the altitude, you slightly unlock altitude motion, move it, then lock it with a one-quarter turn of a screw.

Adrien Poncet
39300 Crotenay — France

Request for Donations

Dear Richard / Enclosed is a letter you asked me to send to *TM*. This letter is addressed to all clubs in the United States. So far we have only received a token response — a few books. What we need are 6- to 8-inch telescopes, eyepieces, star atlases, etc. Thanks for your support. The program needs all the help it can get.

Dear Telescope Maker:

The WAA would like to request your support on a project that was started two years ago — a third world committee. This committee was set up to aid these countries in acquiring materials that can be used in teaching astronomy.

The committee would like to request that individuals and their clubs donate any materials they are not currently using to help these countries. Below is a list of materials needed:

1) Books on astronomy or space
2) Star charts (all kinds)
3) Telescopes 8" and up
4) Eyepieces, finders, telescope-making kits

If you can donate any of these materials, please contact me. You will be helping thousands of people who would love to learn more about astronomy. There are now seven countries who have asked for our support.

And thank you for *your* support.

Robert E. Schalck
Western Amateur Astronomers
25612 Belhaven St.
Hayward, CA 94545

A Variable Eyepiece Holder

Dear Mr. Berry / I hope you find the enclosed sketches useful. They suggest a method of constructing an eyepiece adapter that will accomodate eyepieces of any size between the Japanese stan-

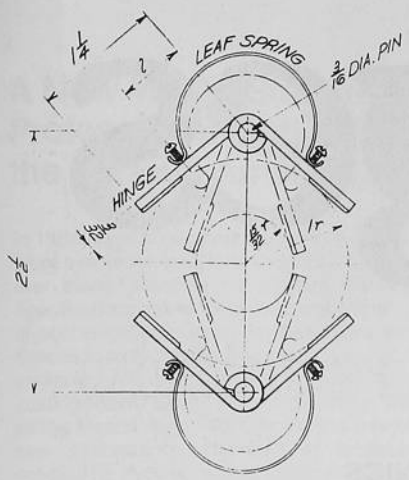
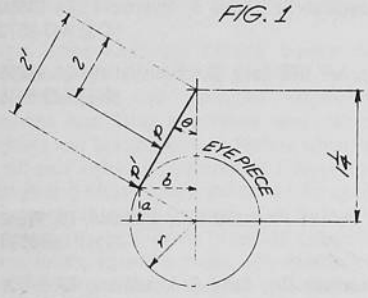


FIG. 1



p = force of leaf spring
$\sin\theta = \frac{r}{1\frac{1}{4}}$ $\quad l' = \theta\cos 1\frac{1}{4}$
p' = force on eyepiece = $p\frac{l}{l'}$
a = force down in sketch = $p'\sin\theta$
b = force across in sketch = $p'\cos\theta$
total force across eyepiece = $4b$
total force up & down on eyepiece = $4a$

FIG. 3

dard and the American 2-inch diameter eyepieces.

The first sketch is looking down on the adapter; had we an eyepiece in the adapter, we would be looking into its eyelens. Two circles are drawn in the center of the sketch, one with radius 15/32", the other with radius 1". Two hinges are shown that actually clamp in the eyepiece barrels indicated by the circles. The leaves of the hinge must rotate freely about their hinge pins, but they must not be loose. The original hinge pins are removed and replaced with new pins that extend vertically down into a common base, shown in the second sketch.

The pins must be straight and should be installed with the aid of a drill-press in order to assure that they are perpendicular to their common base. A circular leaf spring serves to apply pressure to the hinge leaves. Other springs of differing types could possibly be used, but only one spring per hinge should be used to assure forces on each leaf are balanced.

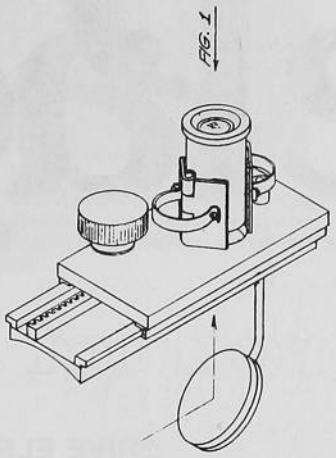


FIG. 2

The working of the adapter should be obvious. The hinge leaves are merely opened more to accommodate eyepieces of larger diameters, up to 2" or so. The geometry of the hinge leaves and springs should assure that any eyepiece placed within the hinge leaves is automatically centered. Since this adapter system is somewhat bulky, a focusing arrangement like that shown in the second sketch is probably the best. The third sketch shows the forces on the barrel of an eyepiece placed between the hinges' leaves.

I am an amateur who enjoys mounting my own eyepiece lenses. I rarely have the correct size of eyepiece tubing laying around, and I don't like limiting myself to standard eyepiece barrel sizes. This adapter allows me greater flexibility in assembling my eyepieces. Such a design might also omit the necessity of buying eyepieces in particular barrel sizes, and of having to slip in adapters especially machined for certain eyepieces.

Rick Blakley
1400 B, Clover Street
Winston-Salem, NC 27101

Maintaining an Older Telescope

Richard / I'd been wondering what to do with my tired 8" f/8 horseshoe-mounted telescope (shown at RTMC '82 and '83). The impregnated Kraft paper tube became brittle and started to crack. Dropping it several times and traveling over rough desert roads hadn't helped. The telescope had reached the point where the optics had began to be a problem to keep aligned.

I liked the design of Geoffrey Chester's Dobsonian in *TM#26*, and I decided that I would get more use out of my old scope if it were a Dob. After pricing the shelf bracket channels he used, I decided to go back to an eight-sided wooden box. I would then have a solid structure, which would be less prone to moisture damage. I could also use up some wood cluttering up the backyard of the apartment.

The box part of the tube will use PVC closet flanges for the altitude trunnions and Teflon for the bearings (nothing new there), and two PVC pipe fitting octagons separated by foam-filled steel pipe (to dampen vibrations). The focuser will be mounted on an aluminum plate with some fiberglass greenhouse window material for a light shield. I'm just starting construction so I will update you later, when the project is completed. Anyway, thanks for *TM#26*.

You may be interested in the current version of my 12.5". The monster pier was part of the tube structure from RTMC '83, the bearings were purchased in the swap meet that same year from the Los Angeles Astronomical Society. The cradle is made from scrap steel and some parts from a CAT-scan table. The whole thing weighs around 400 pounds.

I have a word of advice for anyone using a rack-and-pinion focuser. Apply Locktite or drip some wax or paint on the screws holding the rack to the drawtube. I nearly lost my camera when the screws on mine fell out while I was trying to photograph Comet Halley. Almost ruined my evening. Now I carry extra screws and hardware just in case.

Kristin F. Karalius
1512 West Mercer Lane #2
Phoenix, AZ 85029

Quick Polishing

TM / I have a new method for polishing mirrors. 1.) Mix White Diamond body putty and cream hardener. 2.) Spread over tool. 3.) Wait five minutes. 4.) Quickly put oxide on mirror and press mirror lap to form shape and cut channels.

This method polishes mirrors faster and easier. There is no hot wax or pitch to contend with. This way you will not be burned and the glass will not crack or break.

Wayne E. Blystone
201 N. 3rd St.
Apollo, PA 15613

— Opticians have long known how to polish glass rapidly, but that's not the problem. The job of optical finishing is to produce a precisely shaped surface, and the cold-flow properties of pitch make this possible. It would be interesting to examine the figure of the mirrors you have polished.

■

Blue Pages

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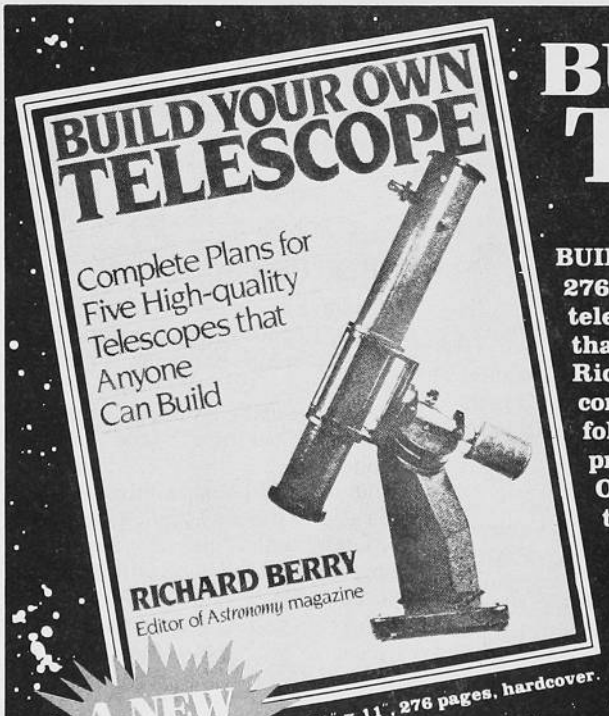

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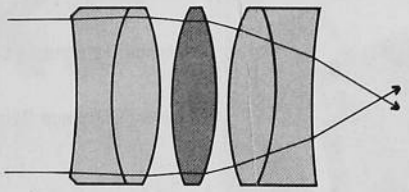
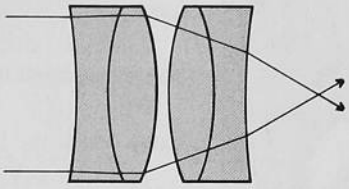
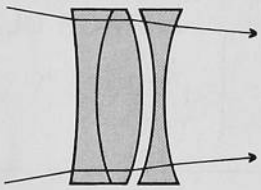


Meade 5-element Super Plössl design: the central lens element enables significant reductions in chromatic aberration and edge-distortions over other premium Plössl designs.



Other premium Plössls: include only the traditional 4-elements.



Meade Series 4000 Barlows: 3 elements, air-spaced, instead of the standard 2 non-air-spaced elements.

Series 4000 Eyepieces and Barlows

Super Plössls (5-elements)	APPARENT FIELD	BARREL DIA.	PARFOCAL
6.4mm	52°	1¼"	Yes
9.7mm	52°	1¼"	Yes
12.4mm	52°	1¼"	Yes
15mm	52°	1¼"	Yes
20mm	52°	1¼"	Yes
26mm	52°	1¼"	Yes
32mm	52°	1¼"	Yes
40mm	44°	1¼"	No
56mm	52°	2"	No
Super Wide Angles (6-elements)			
13.8mm	67°	1¼"	Yes
18mm	67°	1¼"	Yes
24.5mm	67°	1¼"	Yes
32mm	67°	2"	No
40mm	67°	2"	No
Ultra Wide Angles (8-elements)			
4.7mm	84°	1¼"	Yes
6.7mm	84°	1¼"	Yes
8.8mm	84°	1¼" & 2"	Yes
14mm	84°	1¼" & 2"	No
Barlow Lenses (3-elements, air-spaced)			
#140 2X Telenegative Amplifier		1¼"	Yes
#142 2.8X Telenegative Amplifier		1¼"	Yes

Meade 2" Mirror Diagonal: For attachment to Schmidt-Cassegrain telescopes, the 2" Mirror Diagonal permits use of Series 4000 eyepieces with 2" barrels. The 1/10-wave-flat Pyrex mirror, manufactured at the Meade Costa Mesa optical facility, is multi-coated with enhanced aluminum for maximum reflectance. An adapter for 1¼" eyepieces is included.

Where To Buy: Meade Series 4000 eyepieces and Barlows are available from over 600 authorized Meade dealers in the U.S.A. and Canada. Call us toll-free (see below) for your nearest dealer.

Prices: Notwithstanding their performance standards and optical sophistication, Meade Series 4000 eyepieces and Barlows are priced very competitively with other premium oculars and Barlows.

Warranty: All Series 4000 systems are covered by the Meade Limited Lifetime Warranty—the most extensive in the industry. See the Meade catalog for details.

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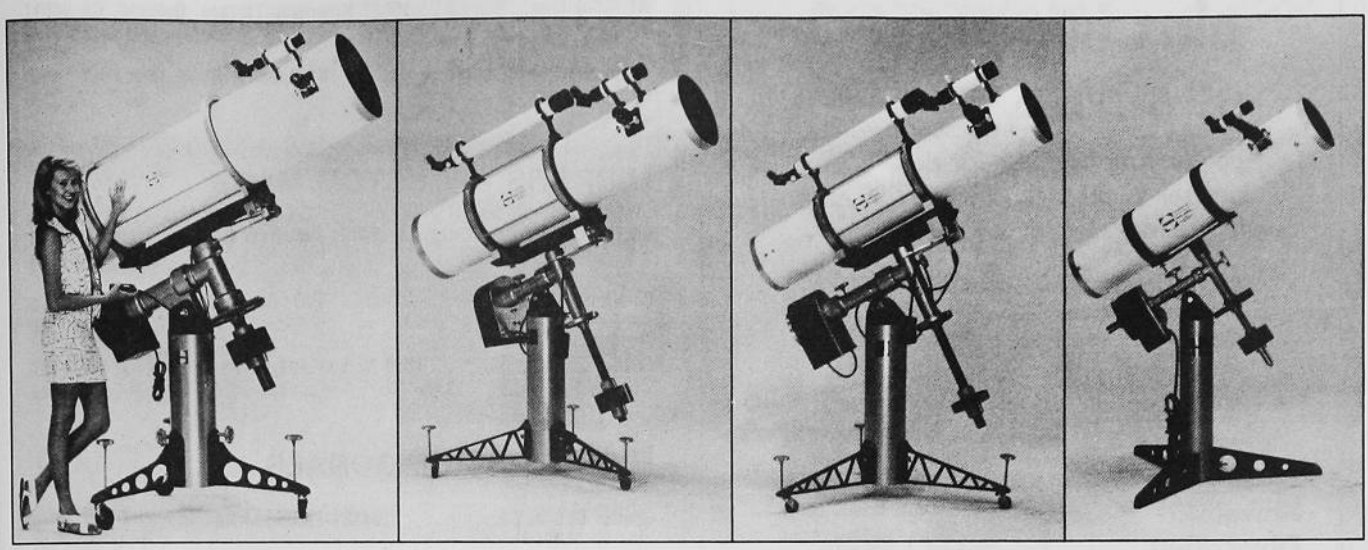

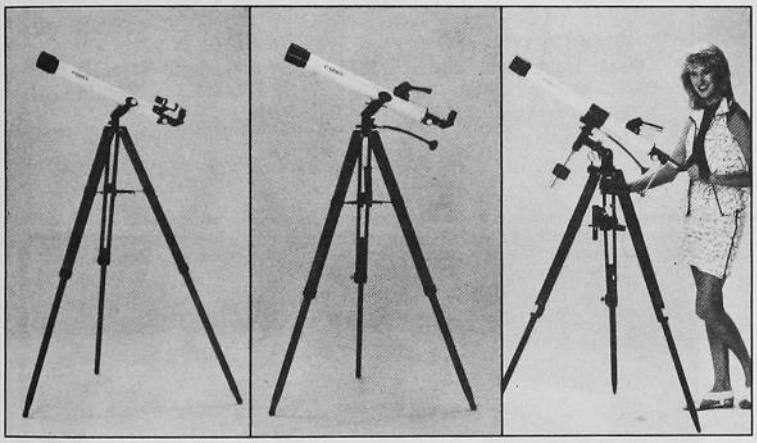

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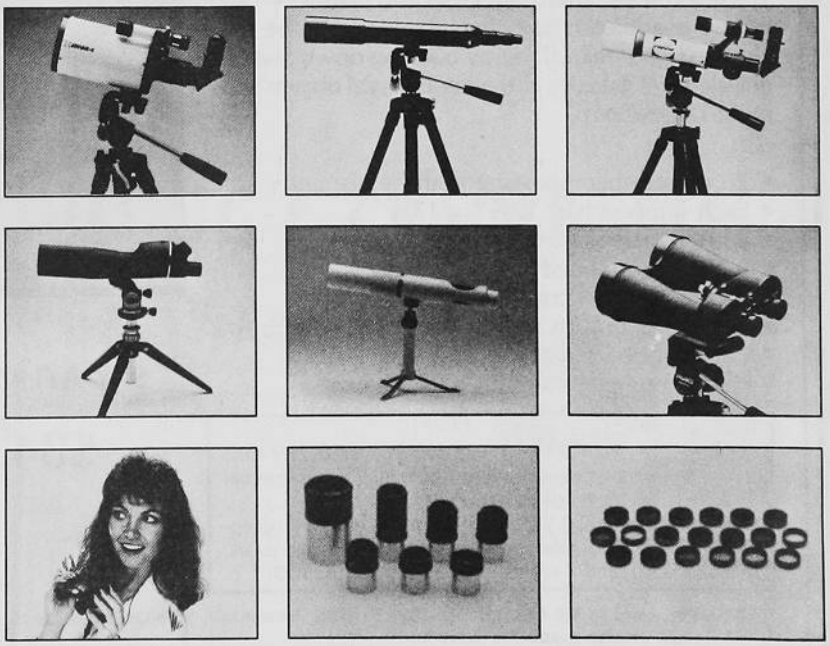

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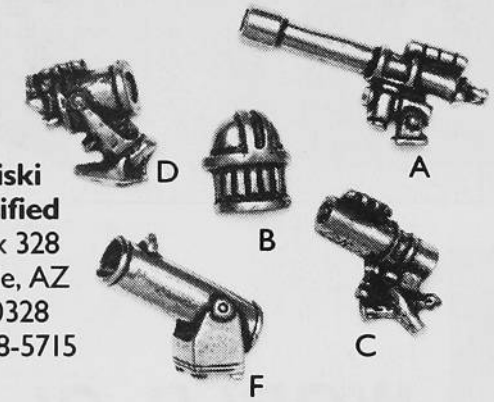

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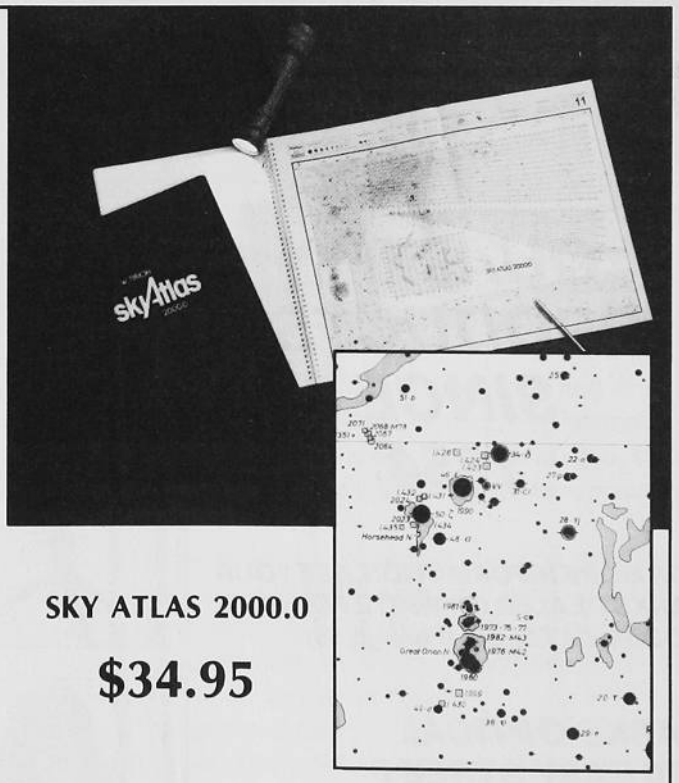

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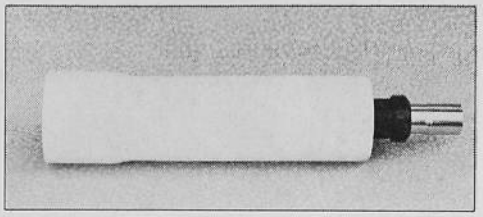

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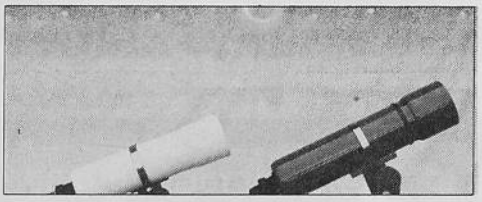

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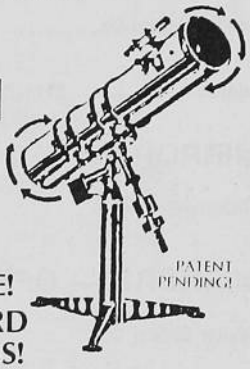

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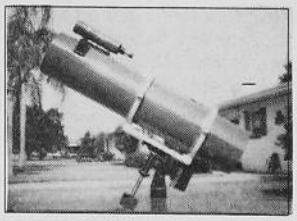

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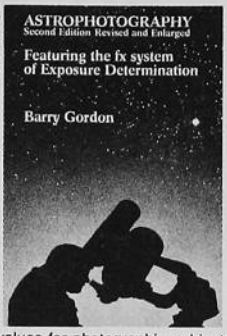

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Starting in 1957, and continuing for nearly 20 years, Allan Mackintosh directed the publication of the "Circulars" for the Maksutov Club. First formed to make a mass purchase of corrector blanks the club soon expanded to become a forum for advanced telescope making techniques. By the time "Circulars" ended when Mackintosh retired to his native England, they totaled nearly 1800 closely typed pages.

Following Mackintosh's suggestion the most significant articles from the circulars have been arranged into two volumes — *Optics and Mechanical*, where together they total 17 chapters of 143 articles taking up more than 600 typeset pages with over 450 illustrations.

What will you find in these books? First, the coverage is not elementary—most of the author's who submitted were accomplished at working under the extreme conditions met within making a Mak (very short radii of curvature and very tight tolerances on thickness, etc.). Second the information is detailed—there was little constraint on the length of individual submissions—if the author had something to say he usually got one, two or even three "Circulars" to tell his story. For example, Norman James Fiberglass Telescope Making Techniques (and his Porter-like drawings) are so detailed that it took 4 circulars to complete. Similarly, Paul Jones article on Optical Glass Edging is the most detailed than you will find in print.

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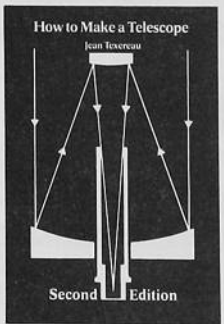

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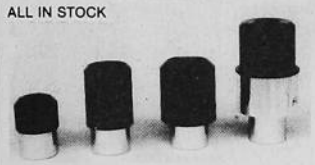

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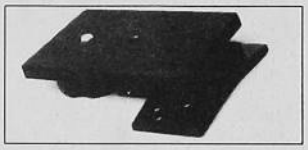

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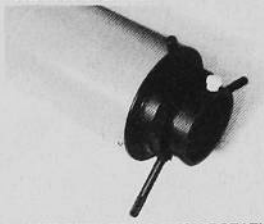

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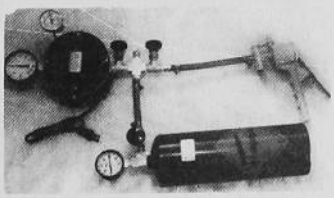

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